U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-297 946

Economics of Disposal of Lime/Limestone Scrubbing Wastes: Sludge/Flyash Blending and Gypsum Systems

National Fertilizer Development Center, Muscle Shoals, AL

Prepared for

Industrial Environmental Research Lab, Research Triangle Park, NC

Feb 79

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/7-79-069

2.

3. RECIPIENT'S ACCESSION NO. PB297946

4. TITLE AND SUBTITLE Economics of Disposal of Lime/Limestone Scrubbing Wastes: Sludge/Flyash Blending and Gypsum Systems

5. REPORT DATE February 1979

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S) J.W. Barrier, H. L. Faucett, and L. J. Henson

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
TVA, Office of Agricultural and Chemical Development
National Fertilizer Development Center
Muscle Shoals, Alabama 35660

10. PROGRAM ELEMENT NO. INE624A

11. CONTRACT/GRANT NO. EPA-IAG-D8-E721-BI

12. SPONSORING AGENCY NAME AND ADDRESS
EPA, Office of Research and Development
Industrial Environmental Research Laboratory
Research Triangle Park, NC 27711

13. TYPE OF REPORT AND PERIOD COVERED Final; 6/77 - 5/78

14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES IERL-RTP project officer is Julian W. Jones, MD-61, 919-541-2489. EPA-600/7-78-023a is an earlier related report.

16. ABSTRACT The report, the second in a series of economic evaluations of flue gas desulfurization (FGD) waste disposal systems, gives results of a study of two processes that produce a soil-like landfill material without using purchased additives: (1) separately collected flyash is blended with dewatered FGD sludge from a limestone scrubbing system; and (2) air-oxidation modifications to a limestone scrubber, which also collects the flyash, produce a high-sulfate sludge (gypsum) which is dewatered and discarded without further treatment. Both processes are being developed: neither has been fully demonstrated. The sludge/flyash blending process had a higher capital investment ($36.40/kW) than the other (as well as untreated ponding and three of four chemical processes evaluated in an ealier study) primarily because of high electrostatic precipitator and process equipment costs; however, the process had lower annual revenue requirements (1.64 mills/kWh) than three of the four chemical processes. The gypsum process had the lowest capital investment ($15.40/kW) of all processes studied to date because of lower process equipment cost and higher waste bulk density; its annual revenue requirements (1.18 mills/kWh) were lower than all processes studied except untreated ponding. Capital investment costs are for mid-1979; annual revenue requirements are for mid-1980.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Waste Disposal	Pollution Control	13B	
Flue Gases	Sludge	Stationary Sources	21B	
Desulfurization	Fly Ash		07A,07D	
Economics	Gypsum		05C	
Scrubbers	Earth Fills		13I	13C
Calcium Oxides	Ponds		07B	08H
Limestone	Electrostatic Precipitators		08G	

18. DISTRIBUTION STATEMENT Unlimited

19. SECURITY CLASS (This Report) Unclassified

20. SECURITY CLASS (This page) Unclassified

21. NO. OF PAGES 209

22. PRICE A10-A01

EPA Form 2220-1 (9-73)

TVA

Tennessee Valley
Authority

National Fertilizer
Development Center
Muscle Shoals AL 35660

PB 297946

TVA Bulletin Y-140

EPA

U.S. Environmental Protection Agency
Office of Research and Development

Industrial Environmental Research
Laboratory
Research Triangle Park NC 27711

EPA-600/7-79-069
February 1979

Economics of Disposal of Lime/Limestone Scrubbing Wastes:
Sludge/Flyash Blending and Gypsum Systems

Interagency Energy/Environment R&D Program Report

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the INTERAGENCY ENERGY-ENVIRONMENT RESEARCH AND DEVELOPMENT series. Reports in this series result from the effort funded under the 17-agency Federal Energy/Environment Research and Development Program. These studies relate to EPA's mission to protect the public health and welfare from adverse effects of pollutants associated with energy systems. The goal of the Program is to assure the rapid development of domestic energy supplies in an environmentally-compatible manner by providing the necessary environmental data and control technology. Investigations include analyses of the transport of energy-related pollutants and their health and ecological effects; assessments of, and development of, control technologies for energy systems; and integrated assessments of a wide range of energy-related environmental issues.

EPA REVIEW NOTICE

This report has been reviewed by the participating Federal Agencies, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Government, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

TVA Bulletin Y-140
EPA-600/7-79-069

February 1979

Economics of Disposal of Lime/Limestone Scrubbing Wastes:
Sludge/Flyash Blending and Gypsum Systems

by

J.W. Barrier, H.L. Faucett, and L.J. Henson

Tennessee Valley Authority
National Fertilizer Development Center
Muscle Shoals, Alabama 35660

EPA Interagency Agreement D8-E721-BI
Program Element No. INE624A

EPA Project Officer: Julian W. Jones

Industrial Environmental Research Laboratory
Office of Energy, Minerals, and Industry
Research Triangle Park, NC 27711

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, DC 20460

i.a

DISCLAIMER

This report was prepared by the Tennessee Valley Authority and has been reviewed by the Office of Energy, Minerals, and Industry, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Tennessee Valley Authority or the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

ABSTRACT

Economic evaluations were made of two flue gas desulfurization waste disposal systems which produce landfill material without purchased additives. Design and economic premises used in previous Tennessee Valley Authority studies were used. Capital investment for the basic sludge - flyash blending process (in which dry flyash is blended with dewatered sludge) is 17.2 $/kW and annual revenue requirements are 1.08 mills/kWh. Including electrostatic precipitator flyash collection the capital investment is 36.4 $/kW and revenue requirements are 1.65 mills/kWh. Capital investment for the gypsum process (in which the scrubber is modified to produce a sulfate sludge which is dewatered and discarded without further treatment) is 10.8 $/kW and revenue requirements are 0.89 mill/kWh. Including scrubber modifications the capital investment is 15.4 $/kW and the annual revenue requirements are 1.18 mills/kWh. These relative cost differencies remain for variations in power plant size, coal sulfur and ash contents, power plant age, distance to the disposal site, and lime instead of limestone scrubbing. In comparison to processes previously evaluated the gypsum process is lower in cost than untreated ponding and chemical-treatment processes. The sludge - flyash blending process is higher in cost than ponding and most chemical-treatment processes.

CONTENTS

Abstract iii
Figures vii
Tables ix
Abbreviations and General Conversion Factors xi

Executive Summary xiii

Introduction 1

Process Background and Description 5
  Sludge - Flyash Blending 6
  Gypsum 6

Design and Economic Premises 7
  Design Premises 7
    Emission Standards 7
    Fuel 8
    Power Plant Design 8
    Power Plant Operation 8
    Flue Gas Composition 9
    Scrubber Design 9
    Sludge Treatment and Disposal 11
    Case Variations 12
  Economic Premises 13
    Capital Costs 14
    Annual Revenue Requirements 16
    Lifetime Revenue Requirements with Declining Operating Schedule 19
    Lifetime Revenue Requirements with Constant Operating Schedule . 20

Systems Estimated 21
  Sludge - Flyash Blending 21
    Field Equipment 22
  Gypsum Process 23
    Field Equipment 28
  Waste Material and Disposal 28

Results 34
  Base Case 34
  Case Variations 44
    Power Plant Size and Operating Schedule 44
    Power Plant Remaining Life 55
    Sulfur in Coal 63
    Ash in Coal 67

Preceding page blank

Lime Versus Limestone 67
Distance to Disposal Site 70
Sludge - Flyash Blending Stoichiometry 73
Sludge - Flyash Layering 73
Waste Production Rate 74
Land Requirements 74
Comparison with Other Waste Disposal Processes 74

Conclusions 81
Base Case 82
Case Variations 83
Power Plant Size 83
Remaining Life 86
Sulfur in Coal 86
Ash in Coal 86
Lime Versus Limestone 87
Distance to Disposal Site 87
Sludge - Flyash Layering 87
Sludge - Flyash Blending 1.3 Stoichiometry 88

Recommendations 89

References 90

Appendices

A. Total Capital Investment and Annual Revenue Requirement Tables - All Processes and Case Variations 93
B. Declining Operating Profile - Lifetime Revenue Requirements . 163
C. Constant On-Stream Time - Lifetime Revenue Requirements . . . 171

FIGURES

Number		Page
1	Sludge - flyash blending. Flow diagram and material balance	24
2	Sludge - flyash blending. Control diagram	25
3	Sludge - flyash blending. Plant layout	26
4	Gypsum. Flow diagram and material balance	29
5	Gypsum. Control diagram	30
6	Gypsum. Layout drawing	31
7	Effect of power plant size on capital investment. New plant	49
8	Effect of power plant size on annual revenue requirements. New plant	50
9	Effect of power plant size on unit capital investment. New plant	51
10	Effect of power plant size on annual unit revenue requirements. New plant	52
11	Effect of power plant size on annual unit revenue requirements. New plant	53
12	Effect of power plant size on annual unit revenue requirements. New plant	54
13	Effect of power plant size on capital investment. New plant operating at constant 7000 hr/yr throughout 30-yr life	56
14	Effect of power plant size on annual revenue requirements. New plant operating at constant 7000 hr/yr throughout 30-yr life	57
15	Effect of power plant size on levelized unit revenue requirements. New plant operating with declining annual operating load over 30-yr life	59
16	Effect of power plant size on levelized unit revenue requirements. New plant operating at constant 7000 hr/yr throughout 30-yr life	61
17	Effect of remaining plant life on capital investment. 500-MW plant	62
18	Effect of remaining plant life on annual revenue requirements. 500-MW plant	64
19	Effect of sulfur content of coal on capital investment. New 500-MW plant	65
20	Effect of sulfur content of coal on annual revenue requirements. New 500-MW plant	66
21	Effect of ash in coal on capital investment. New 500-MW plant	68

FIGURES (continued)

Number Page

22 Effect of ash in coal on annual revenue requirements. New 500-MW plant 69

23 Effect of distance to disposal site on capital investment. New 500-MW plant 71

24 Effect of distance to disposal site on annual revenue requirements. New 500-MW plant 72

25 Effect of sludge rate on annual unit revenue requirements, wet basis 75

26 Effect of sludge rate on annual unit revenue requirements, dry basis 76

TABLES

Number Page

S-1 Base-Case Capital Investment Costs xix
S-2 Base-Case Annual Revenue Requirements xx
S-3 Base-Case Modular Economics xxi
S-4 Summary of Total Capital Investment xxii
S-5 Summary of Total Annual Revenue Requirements xxiii
S-6 Lifetime Revenue Requirements for Declining-Load Schedule . . xxiv
S-7 Summary of Lifetime Revenue Requirements for Constant-Load Schedule xxiv
S-8 Capital Investment for Base-Case Waste Disposal Processes . . xxvii
S-9 Annual Revenue Requirements for Base-Case Waste Disposal Processes xxvii
1 EPA-Sponsored FGD Sludge-Related Projects 3
2 Assumed Power Plant Operating Schedule 9
3 Coal and Flue Gas Compositions and Amounts for Various Sulfur Contents in Coal (500-MW Unit) 10
4 Base-Case Conditions and Case Variations 12
5 Cost Indexes and Projections 15
6 Projected 1980 Unit Costs for Raw Materials, Labor, and Utilities 17
7 Annual Capital Charges for Power Industry Financing 18
8 Sludge - Flyash Blending Base-Case Equipment List 27
9 Gypsum - Base-Case Equipment List 32
10 Quantities of Sludge for Disposal - All Case Variations . . . 33
11 Total Capital Investment Summary - Sludge - Flyash Blending . 35
12 Summary of Revenue Requirements - Sludge - Flyash Blending . . 36
13 Total Capital Investment Summary - Gypsum 37
14 Summary of Revenue Requirements - Gypsum 38
15 Modular Capital Investment - Base-Case Sludge - Flyash Blending 40
16 Modular Annual Revenue Requirements - Base-Case Sludge - Flyash Blending 41
17 Modular Capital Investment - Base-Case Gypsum 42
18 Modular Annual Revenue Requirements - Base-Case Gypsum 43
19 Capital Investment Analysis - Sludge - Flyash Blending 45
20 Annual Revenue Requirements - Sludge - Flyash Blending 46
21 Capital Investment Analysis - Gypsum 47
22 Annual Revenue Requirements - Gypsum 48
23 Capital Investment and Annual Revenue Requirements for Declining- and Constant-Load Conditions, k$ 55
24 Summary of Lifetime Revenue Requirements for Systems Operating on a Declining-Load Schedule over the 30-Year Life of the Power Plant 58

TABLES (continued)

Number		Page
25	Summary of Lifetime Revenue Requirement for Systems Operating at Constant Load of 7000 hr/yr during 30-Year Life of the Power Plant	60
26	Land Requirements and Costs	77
27	Base-Case Cost Comparison of Seven Disposal Alternatives .	78
28	Effect of Case Variations on Total Capital Investment and Annual Revenue Requirements - Sludge - Flyash Blending	84
29	Effect of Case Variations on Total Capital Investment and Annual Revenue Requirements - Gypsum	85

ABBREVIATIONS AND GENERAL CONVERSION FACTORS

ABBREVIATIONS

Btu	British thermal unit
^{o}C	degrees Centigrade
^{o}F	degrees Fahrenheit
ESP	electrostatic precipitator
FGC	flue gas cleaning
FGD	flue gas desulfurization
ft	feet
ft/sec	feet per second
g	gram
gal	gallon
gpm	gallons per minute
hp	horsepower
hr	hour
in.	inch
k	thousand
kg	kilogram
km	kilometer
kW	kilowatt
KWh	kilowatthour
l	liter
lb	pound
M	million
MW	megawatt
sec	second

CONVERSION FACTORS

To convert from English units	To metric units	Multiply by
acre	hectare	0.405
barrels of oil	liters	158.97
British thermal unit	gram-calories	252
degrees Fahrenheit-32	degrees Centigrade	0.5555
feet	centimeters	30.48
square feet	square meters	0.0929
cubic feet	cubic meters	0.02832
feet per minute	centimeters per second	0.508
cubic feet per minute	cubic meters per second	0.000472
gallons	liters	3.785
gallons per minute	liters per second	0.06308
grains (troy)	grams	0.0648
grains per cubic foot	grams per cubic meters	2.288
horsepower	kilowatts	0.7457
inches	centimeters	2.54
pounds	kilograms	0.4536
pounds per cubic foot	kilograms per cubic meter	16.02
pounds per hour	grams per second	0.126
miles	meters	1609.
revolutions per minute	radians per second	0.1047
standard cubic feet per minute (32°F)	normal cubic meters per hour (0°C)	1.695
tons (short)[a]	metric tons	0.90718
tons (long)[a]	metric tons	1.016
tons per hour	kilograms per second	0.252

---

a. All tons, including tons of sulfur, are expressed in short tons in this report.

ECONOMICS OF DISPOSAL OF LIME-LIMESTONE SCRUBBING WASTES:

SLUDGE - FLYASH BLENDING AND GYPSUM SYSTEMS

EXECUTIVE SUMMARY

INTRODUCTION

Flue gas desulfurization (FGD) processes are coming into increasing use by the U.S. electrical power industry to meet sulfur oxides (SO_x) emission-control standards established by the U.S. Environmental Protection Agency (EPA). Most existing and planned FGD processes consist of wet-scrubbing systems using a lime or limestone slurry which reacts with SO_x in the flue gas to produce a waste sludge of calcium sulfite and calcium sulfate. A major problem confronting power plants using this type of FGD process is disposal of the waste, which is difficult to dewater to a solid with acceptable landfill properties. The waste slurry can be ponded, where it eventually settles to a material of doubtful stability and questionable environmental effect. As an alternate approach, it can be mechanically dewatered and chemically treated using purchased additives to produce a waste more amenable to landfill disposal. Flyash can be collected separately and disposed of either separately or with the scrubber waste, or it can be collected in the scrubbers and disposed of as part of the scrubber waste. In addition to the many factors of practicality and cost involved in selection of a disposal method, existing State and Federal regulations and impending more-comprehensive regulations make selection of an effective and satisfactory disposal method a complex and difficult process.

An extensive research and development program supported by EPA is in progress to develop, evaluate, and demonstrate environmentally and economically acceptable methods of dealing with FGD wastes. As a part of these studies, TVA is conducting a series of studies on FGD process economics, a portion of which is a study of waste disposal economics. Based on conceptual designs developed from TVA, industry, process vendor, and EPA studies, capital investment and annual revenue requirement estimates are made for each disposal process studied. A consistent structure of design and economic premises is used to permit comparisons on an equitable basis, and to permit comparisons between systems evaluated in different phases of the studies.

In a previous study the economics of four waste disposal methods were evaluated. Untreated ponding was compared with three proprietary processes in which dewatered FGD sludge is mixed with stabilizing chemicals to improve its landfill characteristics. The chemical-treatment processes were developed by the Dravo Corporation, IU Conversion Systems, Inc., and Chemfix, Inc.

In this study two methods are evaluated which produce a dewatered waste material without the use of purchased additives. Both of these methods, the sludge - flyash blending process and the gypsum process, are under evaluation and development but have not been demonstrated in full-scale industrial use. The scrubbing and dewatering processes are generic designs based on extensive industrial experience and experimental data. The physical properties of the wastes are based on similar information and experimental data from a number of sources.

PROCESS BACKGROUND AND DESCRIPTION

Most scrubbing systems produce a sludge with a high sulfite to sulfate ratio. The sulfite (calcium sulfite hemihydrate, $CaSO_3 \cdot 1/2H_2O$) is more difficult to dewater than the sulfate (calcium sulfate dihydrate, $CaSO_4 \cdot 2H_2O$, which is chemically identical to gypsum) and is less suitable as a landfill material. High-sulfite sludges can be practically dewatered to about 60% solids whereas high-sulfate sludges can be practically dewatered to about 80% solids. At these water contents the sulfite waste is a poor landfill candidate while the gypsum waste is much more soillike.

Two potential waste disposal processes are thus to dewater and then to further stabilize the high-sulfite sludge or to produce a high-sulfate sludge which can be dewatered and disposed of without further treatment. The dewatered sulfite sludge can be blended with dry flyash to further reduce the water content and to provide a stabilizing ingredient. Alternately, the scrubbing system can be modified to produce a more highly oxidized sludge consisting primarily of gypsum.

Sludge - Flyash Blending Process

A disposal alternative which involves dewatered sludge and flyash blending is available to power plants using fuels with suitable ash to sulfur ratios. The process (unlike the Dravo, IUCS, and Chemfix processes in which additive quantities are independent of the fuel ash to sulfur ratio) depends on a relatively high-ash, moderate- to low-sulfur coal. Within these relatively wide ranges, however, it has the advantage that no purchased additives and their handling equipment are needed.

In this study high-sulfite effluent from the scrubber system is dewatered from 15% solids to 60% solids using a thickener followed by a rotary-drum filter. Flyash is collected separately using electrostatic precipitators (ESP) and blended with the dewatered sludge using a conventional mixer. The blended waste is assumed to be a soillike solid which can be handled and transported by conventional earthmoving equipment and trucks.

Gypsum Process

Limestone and lime scrubbing systems can be modified, by the addition of forced-air sparging systems, to produce a high-sulfate sludge. Flyash can be removed in the scrubber with the SO_x without affecting the process. In this study it is assumed that the air-oxidation modification produces a high-sulfate (gypsum) sludge with improved dewatering characteristics. The scrubber effluent is assumed to be 15% solids, which is dewatered to 80% solids in a thickener and rotary-drum filter. The product is assumed to be a soillike material which can be handled in the same manner as the waste from the sludge - flyash blending process.

Waste Disposal

The waste from both processes is loaded into over-the-road trucks and disposed of in an area-fill-type landfill where it is piled, contoured, and covered with soil. Typical landfill equipment and operations are assumed, including landscaping to control seepage and runoff.

Design and Economic Premises

The premises used in this study were developed by TVA and EPA to provide an equitable basis for economic comparisons of FGD processes. Conditions for the base case are representative of typical power-industry conditions. Case variations are used to determine the sensitivity of costs to variations in conditions.

The cost analysis, with two exceptions, begins with the scrubber effluent. In this study costs for separate ESP collection of flyash in the sludge - flyash blending process and for air-oxidation modifications are provided separately so that equitable comparisons can be made with systems using either separate or combined flyash and SO_x removal systems.

Design Premises

For the base-case conditions a new, 500-MW net-output midwestern power plant is used. The design and operation are based on Federal Energy Regulatory Commission data and TVA experience. An operating lifetime of 30 years with a declining schedule totaling 127,500 hours is used. The heat rate is 9000 Btu/kWh.

The fuel used is a typical Eastern U.S. coal with 3.5% sulfur and 16% ash and a heating value of 10,500 Btu/lb as fired. It is assumed that 80% of the ash and 95% of the sulfur is emitted with the flue gas. Flyash and SO_x control systems are assumed to remove flyash and SO_x to meet new-source performance standards (NSPS) of 0.01 and 1.2 lb/MBtu respectively.

Scrubber design is based on TVA experience, power-industry operating experience, and process vendor information. The design is generic, representing most-proven technology rather than a particular installation, and is sized and costed as a fully developed and proven unit. A single mobile-bed scrubber is used in each of four trains on the 500-MW unit. Stoichiometry is 1.5 moles of calcium carbonate to each mole of sulfur removed for the standard limestone scrubber and 1.1 moles of calcium carbonate per mole of sulfur removed for the air-oxidation gypsum process.

The sludge-treatment process consists of a conventional thickener followed by rotary-drum vacuum filtration. The scrubber effluent is assumed to be 15% solids for both processes. Sulfur species in the standard scrubber effluent of the sludge - flyash blending process are assumed to be 85% $CaSO_3 \cdot 1/2H_2O$ and 15% $CaSO_4 \cdot 2H_2O$. In the gypsum process the sulfur species are assumed to be 95% $CaSO_4 \cdot 2H_2O$ and 5% $CaSO_3 \cdot 1/2H_2O$.

The waste from the vacuum filters is assumed to contain 60% solids in the sludge - flyash blending process and 80% solids in the gypsum process. At this stage the gypsum process waste is assumed to have a bulk density of 121 lb/ft^3 and to have the handling characteristics of a loose soil. The sludge - flyash blending process waste is mixed with dry flyash in a blade-type mixer. After mixing it is assumed to have a bulk density of 97 lb/ft^3, a solids content of 74% (base case), and the handling characteristics of a loose soil.

The wastes are stockpiled at the process site for transportation to a disposal site 1 mile away by over-the-road trucks. The disposal site is assumed to be a typical area-fill operation in which conventional earthmoving equipment is used to pile the waste to a depth of 30 feet and cover it with 2 feet of compacted soil contoured to control seepage and runoff. Provision for site maintenance, but not for monitoring of offsite environmental effects, is included. Land requirements are based on the bulk density of the waste and the 30-foot fill depth.

Case Variations

Case variations for both processes consist of 200- and 1500-MW power plant sizes; power plants with 25, 20, and 15 years of remaining life; coal with 2% and 5% sulfur and with 12% and 20% ash; lime instead of limestone as the scrubber absorbent; distances of 5 and 10 miles to the disposal site; and a constant operating schedule of 7000 hr/yr over the life of the plant instead of a declining operating schedule. For the sludge - flyash blending process two additional case variations of separate transport of flyash and sludge with deposit in alternate layers at the disposal site, and a 1.3:1.0 calcium carbonate to sulfur-removed stoichiometry are also included.

Economic Premises

The economic premises are divided into capital investment costs and annual revenue requirements. The economic estimates are made using equipment lists, flow diagrams and material balances, process layouts, and other design and operating conditions. Cost information is based on engineering firm and vendor information, TVA data, and published sources. Cost projections are based on Chemical Engineering cost indices. The premises are based on regulated-utility economics with a 60% debt-40% equity capital structure.

Capital investment costs are divided into direct costs, indirect costs, land, and working capital. The costs are projected to mid-1979, representing a mid-1977 to mid-1980 construction period with 50% expenditure in mid-1979. Direct capital costs cover process equipment, piping and insulation, transport lines, foundations and structural, excavation and site preparation, roads and railroads, electrical, instrumentation, buildings, and trucks and earthmoving equipment. Material and labor costs for fabrication and installation of these items are estimated. These estimates are based on costs obtained from vendors and on related literature information.

Indirect capital costs consist of engineering design and supervision, architect and engineering contractor expenses, construction expenses, contractor fees, contingency, allowance for startup and modifications, and interest during construction. Working capital, and land costs of $3500/acre, are included as separate entries. These estimates are based on current industry practice and authoritative literature sources.

Base-case annual revenue requirements are based on a first-year declining operating schedule of 7,000 hr/yr with 127,500 total operating hours. The costs are projected to mid-1980. Case variations include a constant operating schedule of 7,000 hr/yr with 210,000 total operating hours for the three power plant sizes. In addition, lifetime revenue requirements are included for the three power plant sizes with both declining and constant operating schedules. Revenue requirements are divided into direct costs for raw materials, labor, utilities, equipment fuel and maintenance, and analyses and indirect costs for capital charges and overheads. In these studies no raw materials are required and electricity is the only utility used.

RESULTS

Detailed capital investment summaries for both processes are shown in Table S-1. Detailed annual revenue requirements for the base case are shown in Table S-2. These costs do not include costs associated with separate ESP collection of flyash or air oxidation in the scrubbers. Capital investment for ESP units is $9,614,000 (19.23 $/kW) and annual revenue requirements are $1,975,000 (0.56 mill/kWh). Capital investment for air oxidation is $2,303,000 (4.61 $/kW) and annual revenue requirements are $1,005,000 (0.29 mill/kWh). These costs, and 500-MW-size limestone scrubber capital investment of $36,368,000 (72.74 $/kW) and annual revenue requirements of $11,842,000 (3.38 mills/kWh), can be combined with disposal costs to evaluate complete scrubbing - disposal systems.

Base Case

Capital investment for the base-case sludge - flyash blending process, shown in Table S-1, is \$8,605,000 (17.2 \$/kW). Process equipment cost, excluding flyash collection, is 23% of the total, mobile equipment cost is 7%, and land purchase is 6% of the total. Capital investment for the base-case gypsum process is \$5,411,000 (10.8 \$/kW). Process equipment cost is 22% of the total, mobile equipment cost is 9%, and land purchase is 7% of the total.

Annual revenue requirements for the base-case sludge - flyash blending process, shown in Table S-2, are \$3,772,600 (1.08 mills/kWh). The largest direct cost is disposal operating labor and supervision for solids at 20% of the total revenue requirements, followed by process operating labor and supervision at 12% of the total. Annual revenue requirements for the base-case gypsum process are \$3,117,500 (0.89 mill/kWh). Solids disposal operating labor and supervision is the largest direct cost, at 24% of the total, followed by process operating labor and supervision at 14%. Landfill operations, consisting of land preparation and mobile equipment fuel and maintenance, are a minor element of the annual revenue requirements of both processes.

These costs can be further illustrated by a breakdown into modular units based on processing areas, as shown in Table S-3. Each area represents a separate entity based on function with all costs assigned and calculated in the same manner as the total costs were determined. The effect of the relatively high flyash collection and handling costs, as compared to air oxidation, is evident in both capital investment and annual revenue requirements. Capital investment for flyash collection and handling is 23.7 \$/kW and annual revenue requirements are 0.75 mill/kWh. Capital investment for air oxidation is 4.6 \$/kW and annual revenue requirements are 0.29 mill/kWh. Combined sludge and flyash thickening and filtration increase costs for the gypsum process but these are offset by the lower costs associated with the superior settling and filtration characteristics of the gypsum sludge. Mixing contributes little to overall costs. Disposal capital investment, consisting primarily of land and mobile equipment, is a minor part of the total. Disposal annual revenue requirements, primarily labor and supervision, are, however, a substantial portion of the total.

Case Variations

Capital investments and annual revenue requirements for the case variations of both processes are shown in Tables S-4 and S-5 respectively.

Power Plant Size and Operating Schedule--

Power plant size has a large effect on both capital investment and annual revenue requirements for both processes but does not greatly affect the relative cost relationships of the two processes. Capital investment for the sludge - flyash blending process increases 198% for the 200- to 1500-MW power plant size increase of 650%. The gypsum

TABLE S-1. BASE-CASE CAPITAL INVESTMENT COSTS

	Sludge - flyash blending,[a] total k$	Gypsum,[b] total k$
Process equipment	1,985	1,179
Piping and insulation	139	174
Foundation and structural	242	25
Excavation, site preparation, roads and railroads	53	42
Electrical	345	220
Instrumentation	56	52
Buildings	504	174
Subtotal	3,324	1,866
Services and miscellaneous	50	27
Subtotal excluding trucks and equipment	3,374	1,893
Trucks and earthmoving equipment	581	498
Subtotal direct investment	3,955	2,391
Engineering design and supervision	334	195
Architect and engineering contractor	83	48
Construction expense	686	425
Contractor fees	273	186
Subtotal	5,331	3,245
Contingency	1,066	649
Subtotal fixed investment	6,397	3,894
Allowance for startup and modifications	582	340
Interest during construction	768	467
Subtotal capital investment	7,747	4,701
Land	536	403
Working capital	322	307
Total capital investment	8,605	5,411

Basis: New Midwestern 500-MW plant with 30-year life of 127,500 hours, 7,000 hours first year; coal 3.5% sulfur, 16% ash, removed to NSPS; landfill disposal 1 mile from site. Costs scaled to mid-1979.

a. Flyash collected by ESP, 1.5 limestone stoichiometry, waste 74% solids.

b. Flyash collected in scrubber, 1.1 limestone stoichiometry with air oxidation, waste 80% solids.

TABLE S-2. BASE-CASE ANNUAL REVENUE REQUIREMENTS

	Sludge - flyash blending[a]		Gypsum[b]	
	Total annual revenue requirements, $	% of total annual revenue requirements	Total annual revenue requirements, $	% of total annual revenue requirements
Direct costs				
Conversion costs				
Operating labor and supervision				
Plant	438,000	11.6	438,000	14.0
Solids disposal equipment	744,600	19.7	744,600	23.9
Maintenance - plant labor and supervision, 4% of direct investment	158,200	4.2	95,600	3.1
Landfill operation				
Land preparation	8,700	0.2	6,600	0.2
Trucks (fuel and maintenance)	32,900	0.9	29,800	1.0
Earthmoving equipment (fuel and maintenance)	87,800	2.3	79,400	2.5
Electricity	76,900	2.0	49,300	1.6
Analyses	17,000	0.5	17,000	0.5
Subtotal conversion costs	1,564,100	41.4	1,460,300	46.8
Subtotal direct costs	1,564,100	41.4	1,460,300	46.8
Indirect costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total capital investment less land and working capital	606,600	16.0	368,100	11.8
Average cost of capital and taxes at 8.6% of total capital investment	740,000	19.6	465,300	14.9
Overhead				
Plant, 50% of conversion costs less utilities	743,600	19.7	705,500	22.7
Administrative, 10% of operating labor	118,300	3.3	118,300	3.8
Subtotal indirect costs	2,208,500	58.6	1,657,200	53.2
Total annual revenue requirements	3,772,600	100.0	3,117,500	100.0

Basis: New Midwestern 500-MW plant with 30-year life of 127,500 hours, 7,000 hours first year; coal 3.5% sulfur, 16% ash, removal to NSPS; landfill disposal 1 mile from site. Costs projected to mid-1980.

[a] Flyash collected by ESP, 1.5 limestone stoichiometry, waste 74% solids.

[b] Flyash collected in scrubber, 1.1 limestone stoichiometry with air oxidation, waste 80% solids.

TABLE S-3. BASE-CASE MODULAR ECONOMICS

	Capital investment, $/kW		Annual revenue requirements, mills/kWh	
	Sludge - flyash blending	Gypsum	Sludge - flyash blending	Gypsum
ESP costs	19.2	-	0.56	-
Air-oxidation costs	-	4.6	-	0.29
Flyash handling	4.5	-	0.22	-
Thickening	6.5	5.4	0.25	0.30
Filtration	2.5	3.1	0.11	0.16
Mixing	0.9	-	0.05	-
Disposal	2.8	2.3	0.45	0.43
Total	36.4	15.4	1.64	1.18

process capital investment increases 148% for the same power plant size increase. Most of the improvement in disposal cost per unit of power output is a result of lower process equipment and mobile equipment costs relative to power output at the larger plant sizes. Land costs increased in proportion to power output.

Annual revenue requirements show the same disproportionately smaller increase with increasing plant size. Annual revenue requirements for the sludge - flyash blending process and the gypsum process increase 149% and 113%, respectively, for the power plant size increase of 650%. In this case the cause is smaller increases in both process and mobile equipment operating labor and supervision relative to power plant size increase. Landfill costs increase in proportion to power plant size.

The effect of the constant-load operating schedule on first-year revenue requirements is to increase land requirements, resulting in increased capital investment and annual revenue requirement indirect costs. Capital investment costs for the constant-load operating schedule increased 5% or less for both processes. Increases in first-year annual revenue requirements were 3% or less.

Lifetime revenue requirements for the declining-load schedule are shown in Table S-6 and for the constant-load schedule in Table S-7. The results are shown both as the cumulative actual total and as the cumulative present worth total which is discounted at 11.6% to the initial year. They show the same relative cost relationships between the two processes and between the three power plant sizes as the first-year annual revenue requirements. The declining-load operating schedule average unit revenue requirements, expressed in mills/kWh, are about 35% higher than the constant-load average unit revenue requirements.

TABLE S-4. SUMMARY OF TOTAL CAPITAL INVESTMENT

Case	Total capital investment			
	Sludge - flyash blending[a]		Gypsum[b]	
	k$	$/kW	k$	$/kW
Base case[c]	8,605	17.21	5,411	10.82
Variation from base case				
200 MW	6,126	30.63	3,964	19.94
1500 MW	18,282	12.19	9,826	6.55
Existing, 25-year remaining life	8,528	17.06	5,174	10.35
Existing, 20-year remaining life	8,381	16.76	5,115	10.23
Existing, 15-year remaining life	8,276	16.56	5,076	10.15
2% sulfur in coal	7,356	14.71	4,782	9.56
5% sulfur in coal	10,073	20.10	5,884	11.77
12% ash in coal	7,917	15.83	5,042	10.08
20% ash in coal	9,309	18.62	5,707	11.41
Lime scrubbing process	8,178	16.36	5,315	10.63
5 miles to disposal	8,969	17.94	5,750	11.50
10 miles to disposal	9,334	18.67	6,005	12.01
7000 hr/yr operating profile	8,955	17.91	5,672	11.34
200 MW, 7000 hr/yr operating profile	6,268	31.34	4,093	20.47
1500 MW, 7000 hr/yr operating profile	19,321	12.88	10,603	7.07
Sludge - flyash layering	8,743	17.49	-	-
1.3 stoichiometry	8,160	16.32	-	-

Basis: Midwestern plant location, mid-1979 costs; sulfur and flyash removed to meet NSPS.

a. Landfill disposal of 74% solids material; 1 mile to landfill; trucks used for transport of sludge; flyash removed by ESP.

b. Landfill disposal of 80% solids gypsum; 1 mile to landfill from scrubber facilities; trucks used for transport of sludge.

c. New 500-MW plant; 30-year life; coal 3.5% sulfur and 16% ash; limestone scrubbing process.

TABLE S-5. SUMMARY OF TOTAL ANNUAL REVENUE REQUIREMENTS

Case	Revenue requirements			
	Sludge - flyash blending[a]		Gypsum[b]	
	Annual, k$	Mills/kWh	Annual, k$	Mills/kWh
Base case[c]	3,773	1.08	3,118	0.89
Variation from base case				
200 MW	2,779	1.99	2,327	1.66
1500 MW	6,922	0.66	4,961	0.47
Existing, 25-year remaining life	3,852	1.10	3,143	0.89
Existing, 20-year remaining life	3,876	1.10	3,160	0.90
Existing, 15-year remaining life	3,982	1.14	3,227	0.92
2% sulfur in coal	3,224	0.92	2,707	0.77
5% sulfur in coal	4,282	1.22	3,252	0.93
12% ash in coal	3,617	1.03	3,018	0.86
20% ash in coal	3,965	1.13	3,206	0.92
Lime scrubbing process	3,650	1.04	3,104	0.89
5 miles to disposal	4,425	1.26	3,694	1.05
10 miles to disposal	4,891	1.40	4,286	1.22
7000 hr/yr operating profile	3,801	1.09	3,147	0.90
200 MW, 7000 hr/yr operating profile	2,791	2.00	2,401	1.71
1500 MW, 7000 hr/yr operating profile	7,012	0.67	5,028	0.48
Sludge - flyash layering	3,866	1.10	-	-
1.3 stoichiometry	3,673	1.04	-	-

Basis: Midwestern plant location, 30-year plant life, flyash and sulfur removal to meet NSPS, landfill disposal. Costs scaled to mid-1980.

a. Landfill disposal of 74% solids material; 1 mile to landfill facilities; trucks used for transport of sludge; flyash removed by ESP.

b. Base case: Landfill disposal of 80% solids gypsum; 1 mile to landfill from scrubber facilities; trucks used for transport of sludge.

c. New 500-MW plant; coal 3.5% sulfur, 16% ash; limestone scrubbing process; declining operating profile.

TABLE S-6. LIFETIME REVENUE REQUIREMENTS FOR DECLINING-LOAD SCHEDULE

Case	Cumulative actual lifetime revenue requirements, \$[a]	Lifetime average unit revenue requirements, mills/kWh	Cumulative present worth lifetime revenue requirements, \$[a]	Levelized unit revenue requirements, mills/kWh[b]
Sludge - flyash blending				
200 MW	70,341,600	2.76	23,903,700	2.40
500 MW	96,526,800	1.51	32,801,900	1.32
1500 MW	181,405,400	0.95	61,730,100	0.83
Gypsum				
200 MW	62,063,000	2.43	21,047,100	2.12
500 MW	78,072,400	1.22	26,513,400	1.07
1500 MW	126,375,500	0.66	42,998,600	0.58

Basis: New Midwestern plant; 3.5% sulfur, 16% ash in coal, removed to NSPS; mid-1980 costs; 7,000 hr/yr for 10 years, 5,000 hr/yr for 5 years, 3,500 hr/yr for 5 years, 1,500 hr/yr for 10 years.

a. Discounted at 11.6% to initial year.
b. Equivalent of discounted process cost over life of power plant.

TABLE S-7. SUMMARY OF LIFETIME REVENUE REQUIREMENTS FOR CONSTANT-LOAD SCHEDULE

Case	Cumulative actual lifetime revenue requirements, \$	Lifetime average unit revenue requirements, mills/kWh	Cumulative present worth lifetime revenue requirements, \$[a]	Levelized unit revenue requirements, mills/kWh[b]
Sludge - flyash blending				
200 MW	85,472,400	2.04	25,546,100	2.20
500 MW	118,644,300	1.13	35,420,300	1.22
1500 MW	222,596,600	0.71	66,989,700	0.77
Gypsum				
200 MW	77,691,300	1.85	22,691,000	1.95
500 MW	97,629,500	0.93	28,586,200	0.98
1500 MW	161,159,500	0.51	47,321,000	0.54

Basis: New Midwestern plant; 3.5% sulfur, 16% ash in coal removed to NSPS; mid-1980 costs; 7,000 hr/yr for 30 years.

a. Discounted at 11.6% to initial year.
b. Equivalent to discounted process cost over life of power plant.

Remaining Life--

Capital investment for plants with remaining lifetimes of 25, 20, and 15 years decreased slightly, with age, as a result of decreasing land requirements. Land costs decreased from 1.1 $/kW for the new plant to 0.3 $/kW for the 15-year-old plant in the sludge - flyash blending process and from 0.8 to 0.1 $/kW for the corresponding plants in the gypsum process. These decreases were slightly offset by increased process equipment costs of 0.1 $/kW for the existing plants because of the higher heat rate used. Annual revenue requirements also increased slightly because of increased capital charges.

Sulfur Content of Coal--

Sulfur content of the coal was evaluated at 2% and 5%. In capital investment the largest effects are on process equipment, mobile equipment, and land costs. Capital investment is 14.7 $/kW at the 2% sulfur content and 20.1 $/kW at the 5% sulfur content for the sludge - flyash blending process and 9.6 $/kW and 11.8 $/kW at the same sulfur contents for the gypsum process.

Annual revenue requirements for the sludge - flyash blending process are 0.92 mill/kWh at the 2% sulfur content and 1.22 mills/kWh at the 5% sulfur content. For the gypsum process annual revenue requirements are 0.77 and 0.95 mill/kWh at the same sulfur contents. The increases in direct costs for both processes are largely a result of increases in conversion costs, particularly those related to transportation and landfill operations.

Ash Content of Coal--

Coal ash contents of 12% and 20% have effects on cost similar to the effects of sulfur content. Capital investment for the sludge - flyash blending process is 15.8 $/kW at the 12% ash content and 18.6 $/kW at the 20% ash content. Capital investment for the gypsum process is 10.1 and 11.4 $/kW at the same ash contents. In both processes, process equipment, mobile equipment, and land were the cost elements most affected. Annual revenue requirements for the sludge - flyash blending process are 1.03 mills/kWh at the 12% ash content and 1.13 mills/kWh at the 20% ash content. Annual revenue requirements for the gypsum process are 0.86 and 0.92 mill/kWh at the same ash contents. As in the case of coal sulfur content, the change in direct cost is primarily a result of change in transportation and landfill operation costs.

Lime Versus Limestone--

The use of lime as the scrubber absorbent, with process changes to a 10% solids slurry and a 1.0:1.0 stoichiometry for both processes, has minor effect on the sludge - flyash blending process and a lesser effect on the gypsum process. Capital investment is reduced 0.8 $/kW for the sludge - flyash blending process and 0.2 $/kW for the gypsum process. Reduction of process equipment and land costs, because of the improved stoichiometry, are the main cost elements affected. Annual revenue requirements are reduced .04 mill/kW for the sludge - flyash blending process, but are not reduced for the gypsum process.

Distance to Disposal Site--

Distances of 5 and 10 miles to the disposal site increase capital investment for the sludge - flyash blending process from the base case 17.2 \$/kW to 17.9 and 18.7 \$/kW. For the gypsum process the capital investment increases from the base case 10.8 to 11.5 \$/kW at 5 miles and 12.0 \$/kW at 10 miles. All of the increases are a result of higher mobile equipment costs. Annual revenue requirements for the sludge - flyash blending process are 1.08 mills/kWh for the base case, 1.26 mills/kWh at 5 miles, and 1.40 mills/kWh at 10 miles. Annual revenue requirements for the gypsum process are 0.89 mill/kWh for the base case, 1.05 mills/kWh at 5 miles, and 1.22 mills/kWh at 10 miles. The annual revenue requirements increase is largely the result of increased mobile equipment expense and labor.

Sludge - Flyash Blending Stoichiometry--

A 1.3:1.0 calcium carbonate to sulfur-removed stoichiometry for the sludge - flyash blending process reduces capital investment from the base case 17.2 to 16.3 \$/kW, primarily because of reduced process equipment and land costs. Annual revenue requirements are reduced from the base case 1.08 to 1.04 mills/kWh because of slight reductions in land preparation and mobile equipment costs and indirect costs.

Sludge - Flyash Layering--

Separate transport of dewatered sludge and flyash to the disposal site and deposition of the two materials in separate layers increase capital investment from the base case 17.2 to 17.5 \$/kW. Annual revenue requirements inc[illegible] from the base case 1.08 to 1.10 mills/kWh. The increases are a result of increased mobile equipment costs related to the more complex transportaion and landfill operations.

Comparison to Other Processes

The two processes evaluated in this report can be compared to the untreated-sludge ponding and chemical-treatment processes previously evaluated. In untreated ponding the sludge is pumped directly to a waste pond. In the Dravo ponding process the sludge is dewatered to 35% solids, chemically treated, and ponded. The Dravo landfill process is similar except the settled sludge in the pond is removed to a landfill. Both the IUCS and Chemfix processes mix dewatered 60% solids sludge with chemicals and discard it as landfill.

The capital investment for the seven processes are shown in Table S-8. Annual revenue requirements are shown in Table S-9. Costs for ESP units are included in the sludge - flyash blending process and air-oxidation costs are included in the gypsum process costs.

Major factors affecting the capital investment relationship of the seven processes are pond construction, process equipment, and the added costs for ESP units or air oxidation. Land and mobile equipment costs of the processes differ considerably but have a minor influence on the total capital investment.

TABLE S-8. CAPITAL INVESTMENT FOR BASE-CASE WASTE DISPOSAL PROCESSES

Process	Disposal only, $/kW	Scrubbers and disposal,[a] $/kW
Gypsum	15.4[b]	88.2
IUCS	21.4	94.2
Dravo landfill	25.3	98.1
Chemfix	27.1	99.7
Untreated ponding	34.4	107.2
Sludge - flyash blending	36.4[c]	109.2
Dravo ponding	48.2	121.0

Basis: New 500-MW Midwestern plant; 3.5% sulfur, 16% ash in coal removed to NSPS; 1 mile to disposal site. Costs scaled to mid-1979.

a. Basic limestone scrubber cost is 36,368 k$ (72.7 $/kW).
b. Air-oxidation cost of 2,303 k$ (4.6 $/kW) included.
c. ESP cost of 9,614 k$ (19.2 $/kW) included.

TABLE S-9. ANNUAL REVENUE REQUIREMENTS FOR BASE-CASE WASTE DISPOSAL PROCESSES

Process	Disposal only, mills/kWh	Scrubbers and disposal,[a] mills/kWh
Untreated ponding	0.94	4.32
Gypsum	1.18[b]	4.56
IUCS	1.51	4.90
Sludge - flyash blending	1.64[c]	5.02
Dravo landfill	1.89	5.27
Dravo ponding	1.91	5.30
Chemfix	2.00	5.38

Basis: New Midwestern 500-MW plant; 3.5% sulfur, 16% ash in coal removed to NSPS; 1 mile to disposal site. Costs scaled to mid-1980.

a. Basic limestone scrubber cost is 11,842 k$/yr (3.38 mills/kWh).
b. Air-oxidation cost of 1,005 k$/yr (0.29 mill/kWh) included.
c. ESP cost of 1,975 k$/yr (0.56 mill/kWh) included.

The large pond construction cost is a major factor in the low ranking of the ponding processes. Land costs, distance to the disposal site, or both, would have to increase considerably to offset this disadvantage. The necessity of separate flyash collection is a major disadvantage of the sludge - flyash blending process in comparison to other blending processes.

The gypsum process has several advantages. The absence of flyash or raw material handling and blending equipment, the superior settling characteristics, the favorable stoichiometry, and low costs for air-oxidation modifications combine to reduce process equipment costs. Capital investment is additionally, if slightly, reduced by the high bulk density of the waste. The result is a capital investment considerably lower than the other processes.

Major cost factors in annual revenue requirements of the seven processes are raw material costs; conversion costs, which consist primarily of process and disposal labor and supervision; and ESP or air-oxidation operating costs.

Raw material costs for the chemical-treatment processes are an important element of the annual revenue requirements. Conversion costs of the blending-landfill processes do not differ greatly. Conversion costs for the ponding processes are significantly lower.

The ranking of the blending-landfill processes is a result of combinations of moderate to slight differences in raw material, conversion, and indirect costs. The cost of separate ESP units for the sludge - flyash blending process is largely compensated for by absence of raw material requirements.

The main advantages of the gypsum process are low indirect costs and low air-oxidation costs which combine to produce the lowest annual revenue requirements of the processes evaluated except untreated-sludge ponding.

CONCLUSIONS

The gypsum process has a large advantage over the sludge - flyash blending process in capital investment and a smaller advantage in revenue requirements. This relationship is maintained to slightly varying degrees in all of the case variations studied. The cost differences between the two processes are increased when ESP unit and air oxidation are included.

Base Case

Process equipment costs are the major factor in both capital investment and annual revenue requirements cost differences between the two processes. The sludge - flyash blending process requires equipment for storing and metering flyash and for mixing which is not needed for the gypsum process. Much of the process equipment is smaller in size for the sludge - flyash blending process because flyash does not enter the dewatering process. The thickener, however, is much larger than the gypsum process thickener because of the poorer settling characteristics of the high-sulfite sludge. In contrast, mobile equipment costs for the two processes do not differ greatly. The higher bulk density of the gypsum process waste results in a smaller size of equipment in some cases but not in a reduction in number of units.

Base-case annual revenue requirements are also lower for the gypsum process than for the sludge - flyash blending process, primarily because of indirect costs. Direct costs, consisting entirely of conversion costs, are similar for both processes. Labor and supervision costs are the major cost for both processes, about one-third for the process and two-thirds for transportation and disposal. Other direct costs are relatively minor compared to labor and supervision costs. Landfill operations other than labor are less than 10% of the annual revenue requirements of both processes. Utility costs, consisting entirely of electricity costs, are minor for both processes.

Case Variations

In the range of premise changes used in the case variations the gypsum process capital investment remains approximately three-fifths as large as the sludge - flyash blending process capital investment and the gypsum process annual revenue requirements remain approximately four-fifths as large as the sludge - flyash blending process annual revenue requirements. Case variations affecting process equipment and operating labor and supervision produce large to moderate cost variations. Case variations producing large changes in land and mobile equipment costs have less effect.

Power plant size has a large effect on the capital investment and annual revenue requirements of both processes. Most of the reduction is a result of proportionately smaller increases in process and mobile equipment costs and labor and supervision costs, compared to power-output increases. The use of a constant-load operating schedule of 7000 hr/yr for 30 years has little effect on capital investment and first-year annual revenue requirements. Lifetime revenue requirements for the base-case gypsum process are approximately 80% of those for the base-case sludge - flyash blending process, essentially the same relationship followed by first-year revenue requirements. Remaining lives of 25, 20, and 15 years have little effect on either capital investment or annual revenue requirements. Land requirements is the only capital cost materially affected. Annual revenue requirements are only marginally affected.

Sulfur content of the coal has a moderate effect on both capital investment and annual revenue requirements. Ash content of the coal has an effect similar to sulfur content but to a lesser extent. The major effect is due to process equipment costs with lesser effects due to mobile equipment and land costs. Annual revenue requirements are similarly affected due to higher conversion costs, particularly disposal labor and supervision. The use of lime instead of limestone as the scrubber absorbent reduces capital investment slightly by reducing process equipment size and land requirements. Annual revenue requirements are only slightly affected.

Distance to the disposal site has a moderate effect on capital investment and a large effect on annual revenue requirements. The increases are due to increased mobile equipment costs representing additional trucks, large increases in labor and supervision costs, and very large increases in mobile equipment fuel and maintenance costs. The results indicate that distance to the disposal site is an important consideration in disposal costs if the distances are more than nominal.

Separate transportation of sludge and flyash to the disposal site for deposition in layers slightly increases both capital investment and annual revenue requirements because of the increased complexity of the landfill operation.

The use of a 1.3:1.0 calcium carbonate to sulfur-removed stoichiometry instead of a 1.5:1.0 stoichiometry slightly reduces capital investment and annual revenue requirements because of smaller process equipment sizes and mobile equipment operating costs.

The physical characteristics of the waste also contribute to the cost advantage of the gypsum process by affecting the quantity and volume of material handled and the size of the disposal site. The important factors other than power plant fuel and emission-control conditions which contribute to waste volume are scrubber stoichiometry, waste water content, and bulk density. Although none of these factors alone can, within practical limits, reverse the volume relationship, a combination of improved stoichiometry, bulk density, and dewatering could change the waste volume relationships of the two processes.

In comparison to untreated ponding and the Dravo, IUCS, and Chemfix chemical-treatment processes, the gypsum process has the lowest capital investment and except for untreated ponding the lowest annual revenue requirements. Its main cost advantages are low air-oxidation costs and low process equipment costs. The sludge - flyash blending process is similar in cost to the chemical-treatment landfill processes.

RECOMMENDATIONS

The results of the two sludge disposal economic studies completed by TVA provide a basis of comparison for several disposal alternatives. They also establish major factors which control the cost relationships of various processes under different conditions. Many of these factors are continually changing, however. In addition, regulations affecting disposal requirements could change the procedures and requirements of ponding and landfill operations.

These factors create a need for periodic updating of economic information on waste disposal methods. Updated experimental and operating data, particularly on air-oxidation and dewatering technology, should be incorporated into future studies. Vendor modifications should be included in chemical-treatment processes. The effects of anticipated solid waste disposal regulations should be incorporated into disposal costs and related to process-specific waste characteristics.

ECONOMICS OF DISPOSAL OF LIME-LIMESTONE SCRUBBING WASTES:

WASTE SLUDGE - FLYASH BLENDING AND GYPSUM SYSTEMS

INTRODUCTION

The U.S. electrical power industry uses coal-fired steam generator plants for a large portion of its power generation, a situation expected to continue for at least the next 20 years. Coal-fired facilities are particularly affected by regulations limiting emission of particulate matter and sulfur oxides (SO_x) to the atmosphere. Particulate matter control can be accomplished by several wet or dry processes which remove flyash from the flue gas. Other than the use of low-sulfur coal, which is limited in quantity and geographical distribution, SO_x control requires treatment of the coal before combustion or of the flue gas during or after combustion. An extensive SO_x emission control technology has developed, of which postcombustion flue gas desulfurization (FGD) processes are now the most technically advanced and widely used. Flyash removal can be combined with the FGD process or separate facilities can be used. A variety of FGD processes are under development, including dry absorption and several wet-scrubbing processes. In wet-scrubbing processes, SO_x adsorbed by the scrubbing liquid reacts with an adsorbent to form sulfur salts which can be removed from the system. The sulfur salts can be decomposed to form regenerated absorbent and a usable sulfur compound or they can be discarded as waste. Several regenerable processes are in various stages of application but almost all existing and projected FGD systems consist of nonregenerable wet-scrubbing processes using limestone or lime as the adsorbent and producing a sulfur-salt waste. In 1977 about 30 existing FGD systems scrubbing 10,000 MW and about 60 units planned or under construction to scrub an additional 25,000 MW were over 90% nonregenerable limestone or lime processes (1). The waste produced by these systems presents a major handling and disposal problem (2).

The quantity of sulfur-salt waste produced is quite large. To meet existing emission regulations with limestone scrubbing, for example, a 500-MW power unit burning typical Eastern U.S. coal requires, during its lifetime, removal of over 600,000 tons of sulfur. Disposal of the sulfur-salt waste as untreated sludge requires a 250-acre pond filled to a depth of almost 20 feet. If flyash disposal is included the pond size increases to over 400 acres (3).

The waste sludge withdrawn from the scrubber loop consists of a slurry of about 15% solids. Both the liquid- and solid-phase compositions vary widely, depending on fuel type, combustion conditions, and scrubber design and operating conditions. The solids are characterized by the presence of calcium sulfate dihydrate (gypsum) and calcium sulfite hemihydrate in differing ratios. The sulfate to sulfite ratio is usually less than unity although low sulfur to air ratios, long scrubber holdtimes, or an added forced-oxidation stage may produce near-complete oxidation to sulfate. Unreacted absorbent is often present in appreciable quantities, especially if limestone is used. Flyash is present in varying quantities depending on the efficiency of separate particulate control equipment, or it may be a major component if the scrubber is also used for particulate control. Trace and minor elements, some of which are of particular concern in pollution control, are present in both the liquid and flyash phases (4).

A variety of sludge disposal methods exists, most economically and practically dependent on a number of highly site-specific conditions. The simplest disposal method consists of pumping or transporting the untreated sludge to a ponding area where it eventually settles to a solid of limiting load-bearing capacity and stability containing about 40% to 60% water. The sludge may be mechanically dewatered before disposal to facilitate handling or reduce land requirements, but with much the same resulting waste product.

Alternately the sludge can be chemically or physically treated to improve such properties as stability, load-bearing capacity, erosion resistance, and permeability. Several commercial processes involve addition of materials which produce a series of hydraulic reactions, forming a claylike material (3). Forced oxidation within or as an adjunct to the scrubbing system to produce a high sulfate to sulfite ratio or blending with dry flyash are other possible treatments to improve stability and load-bearing characteristics.

The particular disposal method is dependent on such factors as the type, cost, and proximity of the disposal site; the characteristics of the fuel, combustion, and emission control systems; and a number of environmental considerations. Environmental concerns are of increasing importance because of impending regulations likely to impose additional restrictions on water pollution by runoff and seepage from solid waste disposal sites.

A broad range of investigations are underway to evaluate FGD waste characteristics and disposal methods. As part of its "Control of Waste and Water Pollution from Combustion Sources" program, the U.S. Environmental Protection Agency (EPA) is sponsoring a series of studies (Table 1) to evaluate FGD waste characteristics, disposal methods, and environmental effects. As a part of these studies, the Tennessee Valley Authority (TVA) is conducting economic evaluations of FGD waste disposal processes using design and economic premises developed by TVA and EPA for comparative evaluations of FGD system economics. A previous report (3) compared the economics of the Dravo Synearth, IUCS Poz-O-Tec, and

TABLE 1. EPA-SPONSORED FGD SLUDGE-RELATED PROJECTS

Project	Contractor	Primary area of interest
FGC waste characterization, disposal evaluation, and technology transfer	Arthur D. Little, Inc. Cambridge, Massachusetts	Environmental and technology assessment
Shawnee FGD waste disposal field evaluation	Tennessee Valley Authority Division of Chemical Development Muscle Shoals, Alabama	Environmental assessment
	The Aerospace Corporation El Segundo, California	
Laboratory and field evaluation of FGC treatment processes	U.S. Army Engineer Waterways Experiment Station Vicksburg, Mississippi	Environmental assessment
Attenuation of FGC waste leachate by soils	U.S. Army Material Command Dugway Proving Ground, Utah	Environmental assessment
Establishment of data base for FGC disposal standards	SCS Engineers Long Beach, California	Environmental assessment
Evaluation of FGD waste disposal options	Louisville Gas and Electric Company Louisville, Kentucky	Technology assessment and development
FGD waste leachate - liner compatability	U.S. Army Engineer Waterways Experiment Station Vicksburg, Mississippi	Technology assessment and development
Scrubber waste characterization	Tennessee Valley Authority Energy Research Chattanooga, Tennessee	Technology assessment and development
Dewatering principles and equipment design	Auburn University Auburn, Alabama	Technology assessment and development
Conceptual design-cost studies of alternative methods for FGC waste disposal	Tennessee Valley Authority Office of Agricultural and Chemical Development Muscle Shoals, Alabama	Economic study
Gypsum byproduct marketing studies	Tennessee Valley Authority Office of Agricultural and Chemical Development Muscle Shoals, Alabama	Economic study
Evaluation of alternative FGC waste disposal sites	Arthur D. Little, Inc. Cambridge, Massachusetts	Alternative disposal methods
Scrubbing waste conversion studies	Pullman Kellogg Company Houston, Texas	Utilization methods development
Fertilizer production using scrubbing wastes	Tennessee Valley Authority Office of Agricultural and Chemical Development Muscle Shoals, Alabama	Utilization methods development
FGD waste and flyash beneficiation	TRW Systems Group Redondo Beach, California	Utilization methods development

Chemfix sludge-stabilization processes with untreated ponding disposal of waste from lime and limestone scrubbing systems. These three processes all use dewatering and addition of proprietary additives to improve characteristics of the sludge that contribute to disposal problems. Comparative economics were determined for a number of power plant size and age conditions, fuel sulfur and ash contents, and sludge treatment and disposal variations, permitting economic comparison of the four systems under different conditions.

This study is a continuation of the previous work, using the same design and economic premises and case variations. The economics of two sludge-treatment methods--blending of sludge with dry flyash and forced oxidation to gypsum--are compared. The same cost breakdown is used to permit direct comparison with the results of the previous evaluation.

PROCESS BACKGROUND AND DESCRIPTION

The disposal of physically or chemically treated FGD sludges as a landfill material is an attractive alternative to untreated disposal available to the utility industry. The landfill disposal of sludge can be evaluated for comparison with other alternatives, such as ponding or mine disposal, to estimate the effects of land availability, soil characteristics, environmental regulations, and waste material properties on disposal costs (5, 6). Four waste disposal alternatives evaluated in the earlier economic evaluation by TVA (untreated ponding, IUCS process, Dravo process, and Chemfix process) along with the two alternatives evaluated in this study (sludge - flyash blending and oxidation to gypsum) represent a wide range of disposal options available to the power industry.

The physical characteristics of FGD sludges important in disposal considerations include dewatering characteristics, rewatering potential, bulk density, unconfined compressive strength, and permeability. Most untreated FGD sludges produced in lime and limestone scrubbing systems are not good candidates for landfill materials. Dewatering to the 60% to 70% solids content necessary for adequate stability and handling characteristics is difficult, loss of stability through rewatering is a potential problem, and the compressive strength is marginal for most landfill applications. In general, high-sulfite sludges are more difficult to dewater, less stable, and are susceptable to quasithixotropic behavior under conditions of marginal water contents as compared to sludges with high sulfate to sulfite ratios.

Several commercial chemical-treatment processes are available for FGD sludge treatment to produce a more suitable landfill material. These are in use at several power plants using lime or limestone FGD systems (1) and are under evaluation at the Shawnee EPA Alkali Scrubbing Test Facility (7). They have the capacity to greatly improve dewatered sludge stabilities and compressive strengths as well as, at least in sludges undisturbed after treatment and deposition, to decrease permeabilities. By adjusting the type and extent of treatment the properties of the waste material can also be controlled to meet particular disposal requirements (3). The two processes evaluated in this study are alternate methods of improving dewatered sludge landfill characteristics without the use of purchased additives.

As an alternative to treatment by commercial processes, additional dewatering by blending the sludge with dry flyash or improving dewatering by increasing the sulfate to sulfite ratio are potentially useful methods of improving the landfill characteristics of dewatered FGD sludge. Both these methods are being evaluated in large-scale pilot operations (4, 5) but have not been systematically evaluated in fully operational systems. Both are system-dependent in the sense that they use no independently available additives. Operating or fuel conditions such as extreme ash to sulfur ratios could preclude their use or alter the waste material properties upon which the disposal economics are based.

SLUDGE - FLYASH BLENDING

The alternative involving physical stabilization of dewatered sludge using dry flyash is desirable because it requires only dry flyash as a treatment additive, provides for disposal of both flyash and FGD sludge, and at the same time permits landfill disposal instead of ponding (8). The primary function of the dry flyash from the standpoint of this study is to obtain a final water content lower than that readily obtainable by other methods. At the final water content used, sludge of this type has sufficient compressive strength and stability to be handled as a landfill material.

GYPSUM

The typical waste from a lime or limestone FGD scrubber system contains considerable amounts of calcium sulfite sludge; however, the FGD can be modified to permit oxidation of sulfite to sulfate (gypsum) within a single- or multiple-stage scrubbing loop. The conversion to gypsum is accomplished without addition of catalysts by air sparging at atmospheric pressure (9).

The gypsum slurry produced by this forced-oxidation scrubbing process has improved settling and dewatering properties as compared to sulfite sludge. The gypsum can be mechanically dewatered to an 80% solids material which can be handled with belt conveyors, trucks, and earthmoving equipment and can be disposed of directly as landfill without chemical fixation. The scrubber system also removes flyash which is contained in the sludge and is disposed of with the gypsum. The total quantity and volume of sludge for disposal is significantly reduced over that of the standard lime or limestone process. The reduction in quantity and volume results from improved limestone utilization (1.1 vs 1.5 stoichiometry), dewatering to 80% solids instead of 60%, and higher bulk density.

DESIGN AND ECONOMIC PREMISES

The premises used in this evaluation are the same as those used in the previous study (3) of chemically treated waste. They are based on premises developed by TVA, EPA, and others to provide an equitable basis for economic comparisons of FGD processes. Conditions for the base-case premises are designed to be representative of typical power-industry conditions. Case variations are used to determine the sensitivity of costs to variations in plant size and operating profile, age, fuel, scrubbing conditions, and disposal site location.

With two exceptions costing for this evaluation begins with the scrubber effluent. In the previous study scrubbing costs for the four processes were identical at the same premise conditions and thus were excluded from the economic comparisons. In this study additional costs are included in the sludge - flyash blending process for separate flyash collection by electrostatic precipitators (ESP). In the gypsum process extra costs are included for forced-air oxidation in the scrubber.

DESIGN PREMISES

The utility plant design and operation is based on Federal Energy Regulatory Commission (FERC) historical data (10) and TVA experience. The conditions used are representative of a typical modern boiler for which FGD systems would be most likely to be considered. A midwestern location typical of Illinois, Indiana, and Kentucky is used because the concentration of coal supplies and power plants in this area make it representative of the power industry. The design for both processes is assumed to be proven. No provisions are made for additional spares or special sizing to compensate for unknown design and operating factors.

Emission Standards

New-source performance standards (NSPS) established by EPA (11) specify a maximum emission, based on heat input, of 0.10 lb/MBtu for particulate matter and 1.2 lb/MBtu for SO_2 in large coal-fired boilers. The process design premises used for this study are based on compliance with these standards. Actual SO_x removal efficiencies required vary according to the sulfur content of the coal. The efficiencies required for the sulfur contents and combustion conditions used in this study are:

Sulfur content of coal, % dry weight	Particulate matter removal, % in flue gas	SO_x removal, % in flue gas
2.0	99.5	63
3.5	99.5	79
5.0	99.5	85

Fuel

The coal premises are composites of several hundred samples representing major U.S. coal production areas. To represent the range of sulfur contents in coals now being burned, sulfur contents of 2.0%, 3.5%, and 5.0% dry basis and ash contents of 12%, 16%, and 20% wet basis are used. The coal has a heating value of 10,500 Btu/lb, as fired. The composition and flow rates for the base-case conditions are:

Component	Composition as fired, wt %	500-MW unit requirements, lb/hr
C	57.56	246,800
H_2	4.14	17,700
N_2	1.29	5,500
O_2	7.00	30,000
S	3.12	13,400
Cl	0.15	600
Ash	16.00	68,600
H_2O	10.74	46,000
Total	100.00	428,600

Power Plant Design

Power units up to 1300 MW in size are operated in the United States today. For new units scheduled for startup through 1980 the sizes range from 80 to 1300 MW (12). Although much of the future power production will be from units of 500 MW or larger, many older units as well as some new units of 200 MW or less will continue in operation for many years. The choice of unit sizes used in this evaluation is based on this anticipated power unit size distribution. A single, balanced-draft, horizontal, frontal-fired boiler design is used. A boiler size of 500-MW net output is used for the base case and sizes of 200- and 1500-MW net output (composed of three 500-MW units) are used for the case variations.

Power Plant Operation

An operating life of 30 years is used based on guidelines suggested by FERC (10). The operating schedule based on TVA experience (13) is shown in Table 2. New units are assumed to have a total operating life of 127,500 hours. Existing units 5, 10, and 15 years old are assumed to have remaining operating lives of 92,500, 57,500, and 32,500 hours.

TABLE 2. ASSUMED POWER PLANT OPERATING SCHEDULE

Operating year	Capacity factor, % (nameplate rating)	Annual operating time, hours
1-10	80	7,000
11-15	57	5,000
16-20	40	3,500
21-30	17	1,500
Average for 30-year life	48.5	4,250

Power plant efficiencies vary with size and status. FERC data (14) list heat rates for power units approximately 500 MW in size up to 5 years old which range from 8,800 to 12,800 Btu/kWh. The following heat rates are used in this study:

Unit size, MW	Status	Heat rate, Btu/kWh
200	New	9,200
200	Existing	9,500
500	New	9,000
500	Existing	9,200

Flue Gas Composition

Flue gas compositions are the result of power unit design, fuel, and a variety of operating conditions. The combustion and emission conditions used to determine flue gas composition are based on balanced-draft boiler design and average values for the sulfur content of coal. Flue gas compositions are based on combustion of pulverized coal using a total air rate to the air preheater equivalent to 133% of the stoichiometric requirement. This includes 20% excess air to the boiler and 13% air inleakage at the air preheater. These values reflect operating experience with TVA horizontal, frontal-fired, coal-burning units. It is assumed that 80% of the ash present in coal is emitted as flyash and 95% of the sulfur in the coal is emitted as SO_x. One percent of the SO_x emitted is assumed to be SO_3 and the remainder SO_2.

The coal and flue gas compositions and flow rates are shown in Table 3.

Scrubber Design

Scrubber design criteria are based on TVA operating experience, general power industry operating experience, and information from process and equipment vendors. The designs are generic to the extent that they represent most-proven technology rather than a particular existing

TABLE 3. COAL AND FLUE GAS COMPOSITIONS AND AMOUNTS FOR VARIOUS SULFUR CONTENTS IN COAL (500-MW UNIT)

	S content in coal (dry basis)					
	2%		3.5%		5%	
Coal composition[a,b]	Wt %	Lb/hr	Wt %	Lb/hr	Wt %	Lb/hr
C	58.03	248,700	57.56	246,800	56.89	244,000
H_2	4.17	17,900	4.14	17,700	4.09	17,500
N_2	1.30	5,600	1.29	5,500	1.27	5,400
O_2	7.81	33,500	7.00	30,000	6.40	27,400
S	1.80	7,700	3.12	13,400	4.46	19,100
Cl	0.15	600	0.15	600	0.15	600
Ash	16.00	68,600	16.00	68,600	16.00	68,600
H_2O	10.74	46,000	10.74	46,000	10.74	46,000
	100.00	428,600	100.00	428,600	100.00	428,600

Flue gas composition	Vol %	Lb/hr	aft^3/min (300°F)	Vol %	Lb/hr	aft^3/min (300°F)	Vol %	Lb/hr	aft^3/min (300°F)
N_2	73.68	3,439,000	1,134,000	73.76	3,450,000	1,138,000	73.80	3,443,000	1,136,000
O_2	4.83	257,400	74,350	4.83	258,200	74,590	4.84	257,800	74,460
CO_2	12.44	911,600	191,400	12.31	904,200	189,900	12.20	894,700	187,700
SO_2	0.14	14,500	2,092	0.24	25,130	3,626	0.34	35,920	5,183
SO_3	0.0014	183	21	0.0024	317	37	0.0034	454	52
NO	0.06	3,002	924	0.06	3,009	927	0.06	3,000	924
HCl	0.01	661	168	0.01	661	168	0.01	661	168
H_2O	8.84	265,400	136,100	8.79	264,500	135,600	8.75	262,400	134,600
	100.00	4,892,000	1,539,000	100.00	4,906,000	1,543,000	100.00	4,898,000	1,539,000
Flyash loading, gr/sft^3									
Dry		6.67			6.65			6.66	
Wet		6.08			6.06			6.08	

a. HHV = 10,500 Btu/lb
b. As-fired basis

installation. The lime and limestone systems are based on TVA experience at the Shawnee EPA Alkali Scrubbing Test Facility (15), extensive power industry experience with these systems, and vendor information. Four parallel scrubber trains are used for the 500-MW power units and two trains are used for the 200-MW power units.

A single-stage mobile-bed scrubber design with a presaturator and an exit-gas demister is used. The scrubbing liquid waste effluent is 15% solids in the limestone systems and 10% solids in the lime system.

Base-case scrubber stoichiometry is 1.5 moles of $CaCO_3$ per mole of SO_x removed for the sludge - flyash blending process and 1.1 moles of $CaCO_3$ per mole of SO_x removed for the gypsum process. Case variations in which different stoichiometries are used consist of a sludge - flyash blending process with a 1.3 $CaCO_3$:SO_x mole ratio, a sludge - flyash blending process using lime with a 1.1 CaO:SO_x mole ratio, and a gypsum process using lime with a 1.0 CaO:SO_x mole ratio.

The sulfur species in the waste slurry from the scrubber in the sludge - flyash blending process are assumed to be 85% calcium sulfite hemihydrate ($CaSO_3 \cdot 1/2H_2O$) and 15% gypsum ($CaSO_4 \cdot 2H_2O$). The sulfur species in the waste slurry from the scrubber in the gypsum process are assumed to be 95% gypsum and 5% calcium sulfite hemihydrate.

Sludge Treatment and Disposal

The sludge from the scrubbers is dewatered with conventional thickeners and vacuum filtration. Recovered water is returned to the scrubbing system. After dewatering, the sludge for the sludge - flyash blending process is assumed to have a solids content of 60%. After blending with flyash the solids content is 74% and the bulk density is 1.56 gm/cc (97 lb/ft^3) for the base-case fuel. Solids for fuel and stoichiometry case variations vary from 71% to 82%. The gypsum is assumed to have a solids content of 80% and a bulk density of 1.94 (121 lb/ft^3) after dewatering. Both types of waste are assumed to be a solid, soillike material that can be handled in the same manner as loose soil.

The waste material is loaded on over-the-road-type trucks by wheeled front-end loaders for transportation to the disposal site. Trucking practices are based on information obtained from commercial trucking firms. A distance of 1 mile to the disposal site is used for the base-case condition. Distances of 5 and 10 miles are included as case variations.

The disposal site is assumed to be land suitable for typical sanitary fill use. The size is based on lifetime production of the power plant and a fill depth of 30 feet at bulk densities of 1.56 gm/cc for the sludge - flyash waste blend and 1.94 gm/cc for the gypsum. No allowance is made for in-place compaction. The disposal site operation is an area-fill type consisting of progressive clearing of the site as it fills; leveling, contouring, and compacting the waste as it is dumped;

and periodically covering the waste with 2 feet of compacted soil from an onsite borrow pit. Site maintenance, such as construction of dikes, diverter ditches, and watering to control dust, is also included. The equipment consists of standard dozers, graders, and rollers used in landfill operations. Monitoring for air and water pollution is not included. These are normally a minor portion of current landfill costs.

Case Variations

Case variations, consisting of a change in one design premise while the remainder is kept at base-case conditions, are included to determine the sensitivity of the process economics to operating condition ranges normally encountered in industry practice. The case variations used in this study are shown in Table 4.

TABLE 4. BASE-CASE CONDITIONS AND CASE VARIATIONS

		Case variations	
Premise condition	Base case	Sludge - flyash blending	Gypsum
Both processes			
Power plant size, MW	500	200, 1,500	200, 1,500
Remaining life, yr	30	25, 20, 15	25, 20, 15
Lifetime operating hours	127,500	210,000	210,000
Sulfur in coal, %	3.5	2, 5	2, 5
Ash in coal, %	16	12, 20	12, 20
Miles to disposal site	1	5, 10	5, 10
Absorbent	Limestone	Lime[a]	Lime[b]
Sludge - flyash blending			
Moles $CaCO_3$:S removed	1.5:1.0	1.3:1.0	
Blending	Mechanical	Layering	
Gypsum			
Moles $CaCO_3$:S removed	1.1:1.0		

[a] A 1.3:1.0 CaO:S removed stoichiometry and a 10% solids scrubber effluent is used for this case variation.

[b] A 1.0:1.0 CaO:S removed stoichiometry and a 10% solids scrubber effluent is used for this case variation.

A case variation is included for the sludge - flyash blending process in which the dewatered scrubber waste and flyash are not mechanically blended but are trucked separately to the disposal site and deposited in alternate layers. The same trucking and disposal site operations are used for this case as are used for the mechanical blending cases. For the purposes of this evaluation the dewatered sludge is assumed to be sufficiently dewatered to load, truck, and dump as a solid.

ECONOMIC PREMISES

The economic premises are divided into capital investment costs for installation of the system and annual revenue requirements for its operation over the life of the power plant. The premises are further divided into sections to facilitate calculation and to establish cost areas for comparison and analysis. Criteria are used which define cost indexes; land, raw material, utilities, and energy costs; capital charges; and other factors required for comparative results. The estimates are made using equipment lists, flow diagrams, material balances, various layouts for electrical equipment, piping, and instrumentation, plot plans, and other design and operating information. Capital cost information for major equipment items is obtained from engineering-contracting, processing, and equipment companies; TVA purchasing and construction data; and authoritative publications on costs and estimating (16-22). Minor equipment costs are based on literature sources or derived as a function of major equipment costs. Revenue requirements are based on current labor and supervisory rates, purchased power costs, costs derived from literature sources, and current industrial practice.

The premises are designed to represent projects in which design begins in mid-1977 and construction is completed in mid-1980, followed by a mid-1980 startup. Capital costs are assumed 50% expended in mid-1979. Capital costs are projected to mid-1979 and revenue requirements are projected to mid-1980. Scaling to other time periods can use mid-1979 as the basis for capital costs and mid-1980 as the basis for revenue requirements.

The premises are based on regulated utility economics which allow the power company to earn a specified return on investment. Regulation, based on FERC guidelines for accounting and rates for interstate transactions, is usually the responsibility of state or local agencies (10). The sludge disposal system cost is combined with the total power plant investment and, therefore, increases the rate base upon which the utility return on investment is based. Thus, a return on equity must be included in any process evaluation under regulated economics. This "cost-of-investment money" is added to the disposal system revenue requirements as part of capital charges. The capital structure is assumed to be 60% debt and 40% equity. Interest on bonds is assumed to be 10% and the return to stockholders 14%.

Capital Costs

Capital costs are categorized as direct investment, indirect investment, contingency, other capital charges, land costs, and working capital. Total fixed investment consists of the sum of direct and indirect capital costs and a contingency based on direct and indirect investment. Total depreciable investment consists of total fixed investment plus the other capital charges. Investment costs are projected from historical Chemical Engineering annual cost indexes (23, 24) as shown in Table 5. The costs are based on construction of a proven design and an orderly construction program without delays or overruns caused by equipment, material, or labor shortages.

Mobile equipment is assigned a 6-year life, based on industry practice. Replacement is covered by an increased interim replacement allowance in revenue requirements.

Direct Investment--

Direct capital costs include all costs, excluding land, for materials and labor to install the complete waste disposal system. Included are site preparation, excavation, buildings, storage facilities, landscaping, paving, and fencing. Also included is 6600 feet of paved road for all cases. Process equipment includes all major equipment and all equipment ancillary to the major equipment, such as piping, instrumentation, electrical equipment, and vehicles. Services, utilities, and miscellaneous costs involved in construction are estimated as 1.5% of the direct investment.

Indirect Investment--

Indirect investment costs consist of various contractor charges and fees and construction expenses. The following cost divisions and determinations are used.

Engineering design and supervision--This cost is calculated as a function of the complexity of the system as determined by the number of major equipment items, excluding mobile equipment. The formula used is:

$$\text{Engineering design and supervision} = (8900)(1.294)(\text{number of major equipment pieces})$$

Architect and engineering contractor expense--This expense is calculated as 25% of the engineering design and supervision costs for major equipment items.

Construction expense--This expense includes temporary facilities, utilities, and equipment used during construction. The expense is calculated as a function of direct investment:

$$\text{Construction expense} = 0.25\,(\text{direct investment excluding landfill equipment in M\$})^{0.83}$$

TABLE 5 . COST INDEXES AND PROJECTIONS

Year	1970	1971	1972	1973	1974	1975	1976[a]	1977[a]	1978[a]	1979[a]	1980[a]	1981[a]
Plant	125.7	132.3	137.2	144.1	165.4	182.4	197.9	214.7	232.9	251.5	271.6	293.3
Material[b]	123.8	130.4	135.4	141.9	171.2	194.7	210.3	227.1	245.3	264.9	286.1	309.0
Labor[c]	137.4	146.2	152.2	157.9	163.3	168.6	183.8	200.3	218.3	237.9	259.3	282.6

[a] Projections.

[b] Same as index in Chemical Engineering for "equipment, machinery, supports."

[c] Same as index in Chemical Engineering for "construction labor."

Contractor fees--Direct investment is also used to determine contractor fees:

$$\text{Contractor fees} = 0.096 \text{ (total direct investment in M\$)}^{0.76}$$

Contingency--

Contingency is 20% of the sum of direct investment and indirect investment.

Other Capital Charges--

Other capital charges consist of an allowance for startup and modifications and interest during construction. The allowance for startup and modifications is 10% of the total fixed investment excluding mobile equipment. Interest during construction is 12% of the total fixed investment. It is based on the simple interest which would be accumulated at 10%/yr under the premise construction and expenditure schedule, assuming a 60% debt-40% equity capital structure.

Land--

Total land requirements, including the waste disposal area, are assumed to be purchased at the beginning of the project. A land cost of $3500/acre is used.

Working Capital--

Working capital consists of money invested in raw materials and supplies, products in process, and finished products; cash retained for operating expenses; accounts receivable; accounts payable; and taxes payable. For these premises, working capital is assumed to be equivalent to the sum of 7 weeks of direct costs and 7 weeks of overhead costs.

Annual Revenue Requirements

Annual revenue requirements are based on a 7000 hr/yr operating schedule using the same operational profile and remaining life assumptions that were used for the power plant design premises. Costs are projected to 1980 dollars to represent a mid-1980 startup. The revenue requirements are divided into direct costs for raw materials and conversion and indirect costs for capital charges and overheads. No raw materials were required in this study.

Direct Costs--

Projected direct costs for labor and electricity are shown in Table 6. Operating labor and supervision is based on the quantity, size, and complexity of the major process equipment. Labor for analyses is based on the number of chemical analyses and physical tests needed for process control. Electrical requirements are determined from the operating horsepower of electrical equipment. The rates are based on purchase from an independent source with full capital recovery provided and are adjusted for the quantity used.

TABLE 6. PROJECTED 1980 UNIT COSTS

FOR RAW MATERIALS, LABOR, AND UTILITIES

			$/unit
Labor			
Operating labor			12.50/man-hr
Analyses			17.00/man-hr
Mobile equipment			17.00/man-hr
	200 MW	500 MW	1500 MW
Utilities			
Electricity, kWh	0.031	0.029	0.027

Fuel and maintenance costs for mobile equipment are based on information from companies operating similar disposal and transportation systems. A cost of $0.16/ton of waste is used for earthmoving equipment. Truck rates for the different distances are:

Distance traveled, miles	$/ton of waste
1	0.06
5	0.20
10	0.39

Landfill operation costs are assigned a value of $1700/acre of landfill required. These costs are allocated by acreage actually used--filled to 30 feet and covered with soil--during the period costed.

Other maintenance costs are based on the direct investment costs. They are adjusted for the size and complexity of the system (based on operating experience with the systems or similar operations) and are assumed to be constant over the life of the plant, the increase in costs balanced by the decline in operating hours. Maintenance costs of 4% of the direct investment were used for all conditions.

Indirect Costs--

Indirect costs consist of capital charges and overheads. A summary of capital charges, based on regulated utility economics, is shown in Table 7. Straight-line depreciation is used, based on the remaining life of the power plant when the FGD system is installed. Following FERC recommendations (10), an allowance for interim replacement is included. This allowance is increased to 2.1-2.5%, depending on age of the power plant, from the usual average of about 0.35% because of the unknown life span of FGD systems and the short life (6-year) of the mobile equipment. The insurance and property tax allowance, based on

TABLE 7. ANNUAL CAPITAL CHARGES FOR POWER INDUSTRY FINANCING

	Percentage of total depreciable capital investment			
Years remaining life	30	25	20	15
Depreciation-straight line (based on years remaining life of power unit)	3.3	4.0	5.0	6.7
Interim replacements (equipment having less than 30-yr life)	2.5	2.4	2.3	2.1
Insurance and property taxes	2.0	2.0	2.0	2.0
Total rate applied to original investment	7.8	8.8	9.3	10.8

	Percentage of unrecovered capital investment[a]
Cost of capital (capital structure assumed to be 60% debt and 40% equity)	
Bonds at 10% interest	6.0
Equity[b] at 14% return to stockholder	5.6
Income taxes (Federal and State)[c]	5.6
Total rate applied to depreciation base	17.2[d]

a. Original investment yet to be recovered or "written off."

b. Contains retained earnings and dividends.

c. Since income taxes are approximately 50% of gross return, the amount of taxes is the same as the return on equity.

d. Applied on an average basis, the total annual percentage of original fixed investment for new (30-yr) plants would be 7.8% + 1/2 (17.2%) = 16.4%.

FERC practice, is 2.0% of the total depreciable capital investment. Cost of capital is based on the assumed capital structure.

Methods of calculating overheads vary. The method used in these premises is based on information from several sources (17-20). Plant overhead is assumed to be 50% of the total conversion cost less the cost of utilities. Utilities are excluded to avoid overcharging energy-intensive processes. Administrative overhead is assumed to be 10% of the total labor and supervision cost.

Lifetime Revenue Requirements with Declining Operating Schedule

Annual revenue requirements are estimated using the assumption that annual operating time for the disposal system is 7000 hr/yr. These estimates are suitable for comparing processes and measuring the effect of process variable changes. Also, they represent operating profiles similar to those during the early years of a plant's life. However, most power units have a declining load over their life and rarely operate in later years at the 7000 hr/yr level assumed for the annual revenue requirement calculations. Since revenue requirement estimates are needed which reflect the operating profiles of older plants, lifetime revenue requirement estimates are calculated using the declining operating schedule previously described. These estimates consider the variations in capital charges and operating profile with plant age.

Capital charges--The portion of indirect costs that reflects the cost of capital and taxes is based on nondepreciated capital investment. A computer program is used to calculate the revenue requirements for each year over the plant life. Straight-line depreciation is used and capital charges decrease uniformly over the life of the disposal system.

Operating profile--The actual quantities affecting direct costs (electricity, operating labor and supervision, maintenance, and analyses) are estimated to calculate annual revenue requirements for each disposal system based on a 7000 hr/yr annual operating time. As the plant's remaining life decreases, the operating profile of the plant and these quantities also decrease. The projected costs for these items are modified to show the effect of decreased operating load on revenue requirements. The annual quantities of each item are scaled proportionally to the annual operating hours for the plant. Annual quantities for operating labor and supervision and overhead charges are scaled proportionally to the annual operating hours raised to the 0.5 power.

The direct charges for maintenance are scaled proportionally to the annual operating hours raised to the 0.6 power. These adjustments to annual revenue requirements to yield lifetime revenue requirements provide information for more accurately estimating revenue requirements for later years of the disposal system life.

In this study estimates are included to show lifetime revenue requirements for a declining operating schedule over a 30-year life as discussed in the design premises. Estimates are made for 200-, 500-, and 1500-MW plants for each sludge disposal process.

Lifetime Revenue Requirements with Constant Operating Schedule

The capacity of a power plant is sometimes held constant or altered with time by adding new generating units as the capacity of older units is reduced by age. When this occurs, the capacity of the disposal system must be sized on the basis of the larger power plant waste disposal requirements as compared to a declining operating schedule.

The annual values with a constant operating schedule are based on average capital charges over a 30-year plant life and a revised capital investment using an adjusted landfill area as compared to a declining profile-type operation. The lifetime values are based on declining capital charges and the same revised capital investment.

In this study estimates are included to show the annual and lifetime revenue requirements for plants with a constant annual operating load of 7000 hours over a 30-year life. Estimates are made for 200-, 500-, and 1500-MW plants for each sludge disposal process.

SYSTEMS ESTIMATED

The conceptual designs for the processes are developed from material balances, major equipment lists, and flow and layout diagrams, using the design premises as specifications. From these, estimates of field equipment such as piping, electrical equipment, instrumentation, structures, site preparation, buildings, services, land requirements, and mobile equipment requirements are made.

With two exceptions the designs are limited to the dewatering and disposal requirements for the processes. The sludge - flyash blending process requires dry flyash which must be collected separately rather than in the scrubber. In this process ESP unit installation and operation are included in the waste disposal system. In the gypsum process the air-oxidation equipment installation and operation are included in the waste disposal system.

The economic estimates are based on the conceptual design and the economic premises. For each case a capital cost estimate and a first-year annual revenue requirement estimate were made. In addition, lifetime revenue requirements were estimated for the base case and the two plant-size case variations for each process using both constant and declining operating schedules.

The lifetime economic results are given for each process as both cumulative actual and cumulative discounted costs (discounted at 11.6% cost of money to the initial year). The results are also given as the lifetime average increase and the levelized increase in unit revenue requirement expressed as $/ton coal burned, mills/kWh, $/MBtu heat input, and $/ton sulfur removed. As the name implies, the lifetime average increase in unit revenue requirement is simply an average unit revenue requirement obtained by dividing the lifetime revenue requirement by the lifetime number of units, such as tons of coal burned. Levelized unit revenue requirements are obtained by dividing the discounted process costs over the life of the power unit by the discounted number of units. They are the more significant costs because they include the effect of time on both money and units of measure.

SLUDGE - FLYASH BLENDING

The scrubber system 15% solids effluent is pumped to an agitated thickener feed tank. From this tank the slurry is pumped to a thickener where the slurry is increased to 35% solids. Thickener underflow is fed to vacuum filters for additional dewatering to 60% solids. Excess water from the dewatering steps is returned to the scrubber system. Flyash is collected by ESP units, whose costs are also given, and pneumatically conveyed to storage bins near the sludge-treatment facilities. The dry flyash and dewatered sludge are blended using a blade-type mixer for all but the layering case variation. Belt conveyors are used to feed the filter cake to the mixer and to convey the blended product to a small pile near the dewatering system for transportation to the disposal site. The transportation and disposal system is basically the same for each process and is discussed following the description of the gypsum process.

Field Equipment

The equipment items other than process equipment are piping, electrical, instrumentation, excavation and site preparation, buildings, roads, earthmoving equipment, and services. The method for estimating the cost of each of these is described below.

Piping--

Carbon steel pipe and gate valves are used for all waterlines. Slurry lines are stainless steel pipe for lines under 3 inches in diameter and are rubber-lined carbon steel for larger lines. Strainers are stainless steel for pipes under 4 inches in diameter and rubber-lined carbon steel for pipes over 4 inches in diameter.

Foundations and Structural--

Concrete foundations for each equipment item are estimated according to equipment sizes. Structural costs are estimated based on the size and weight of the structure.

Electrical--

The electrical cost is divided into four sections: (1) cost of feeder cables from the power plant transformer yard to the sludge disposal facilities, (2) transformer costs for each area, (3) costs of power supply from area field modules to individual motors, and (4) motor control costs between remote control center, field equipment location, and individual motors. Total connected motor horsepower is used to establish costs for the feeder cables and transformers. Costs for power supply and motor controls are based on individual motor sizes and the number of connected motors. A typical layout is assumed for the disposal system in reference to the power plant transformer yard, remote control center, and other areas.

Instrumentation--

Instrumentation costs are based on fixed costs for instruments which do not change in size and cost with equipment size variations and variable costs for instruments which increase in size and cost as equipment and pipe sizes increase. Each of these costs may be dependent upon the number of equipment items, such as pumps, feeders, mixers, conveyors, filters, and thickeners. Costs are included for control valves, graphic boards and panelboards, annunciators, air dryers and piping, and instrument cable and wiring systems.

Excavation and Site Preparation--

The excavation and site preparation requirements depend upon the number of items and the type and size of equipment. Estimates are based on the number of cubic yards of material that is moved in each case.

Buildings--

A control-room building and an equipment building are required for all cases. The same size control-room building (40 ft wide by 40 ft long by 12 ft high) is used for all cases. The equipment building is 50 feet wide by 75 feet long by 40 feet high for 200- and 500-MW plants, and 75 feet wide by 100 feet long by 40 feet high for the 1500-MW plants.

Services--

The cost of services for each case was estimated to be 1-1/2% of direct investment costs. This cost includes vehicles, maintenance and instrument shop equipment, laboratories, lockers, offices, restrooms, storage area, parking area, walkways, landscaping, fencing, and security allocated to the disposal system area by the power plant.

Roads--

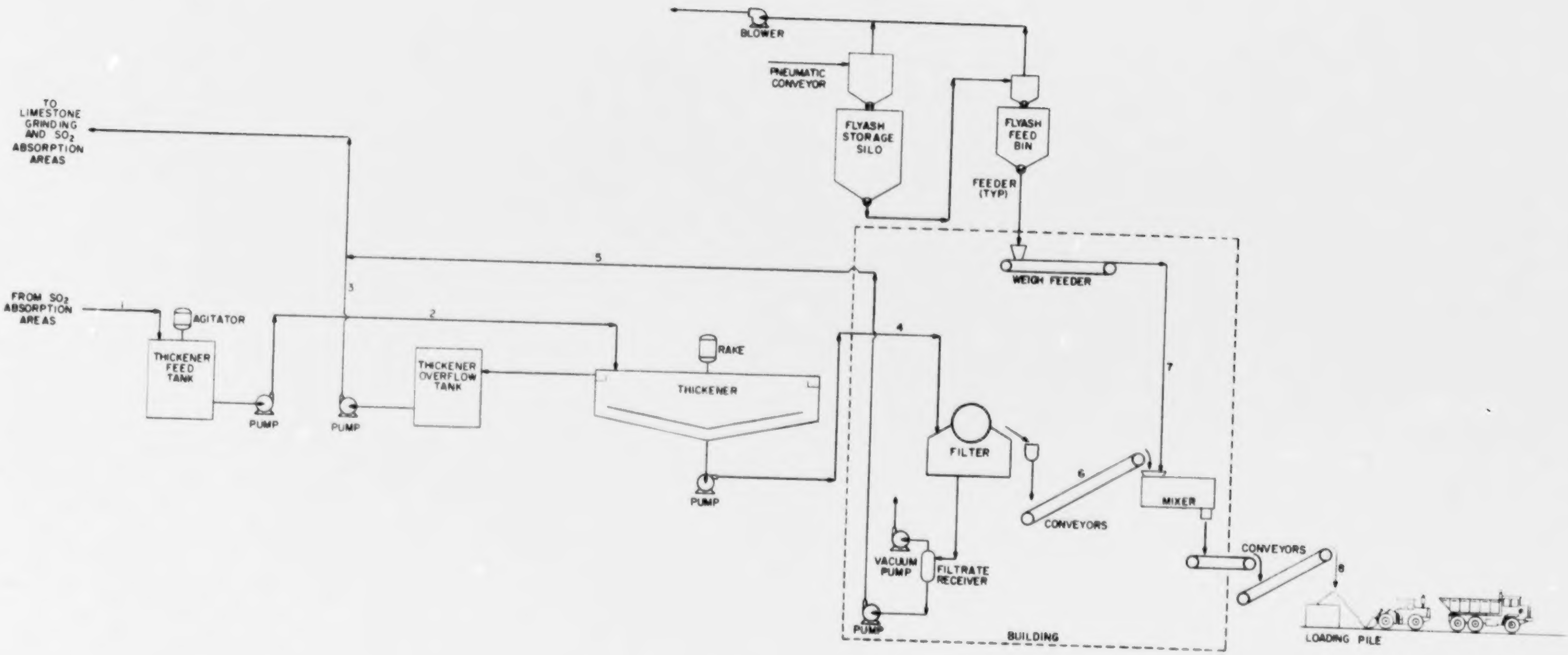
All cases are estimated to require 6600 feet of hard-surface roadway for access to the disposal area and process equipment. Roads are required for the truck transport of waste to the landfill located 1 mile from the scrubber facilities.

A flow diagram and material balance for the base case is shown in Figure 1. The control diagram and layout drawings for this process are shown in Figures 2 and 3. All major equipment items for the sludge - flyash blending base case are included in Table 8.

GYPSUM PROCESS

Additional oxidation in the scrubber system to provide a 95% oxidation to gypsum is included in this system. This consists of addition of air-sparging tanks and equipment in the scrubber liquid loop. Additional costs for the installation and operation of the forced-air oxidation are given for inclusion in the disposal system costs for this process.

The dewatering system for the gypsum process is similar to the sludge dewatering process. An 8-hour-capacity hold tank receives scrubber effluent and feeds thickeners and rotary drum vacuum filters which successively dewater the 15% solids sludge to 35% and 80% solids waste. The recovered water is returned to the scrubber system. The size of the thickeners and filters is adjusted for the higher settling rate and improved filtration characteristics of the sludge relative to high-sulfite sludges. The filter cake is transported by belt conveyor to a waste pile for transportation to the disposal site, as described in the following section.


TO LIMESTONE GRINDING AND SO_2 ABSORPTION AREAS
FROM SO_2 ABSORPTION AREAS
1
AGITATOR
THICKENER FEED TANK
PUMP
2
3
PUMP
THICKENER OVERFLOW TANK
RAKE
THICKENER
PUMP
5
4
BLOWER
PNEUMATIC CONVEYOR
FLYASH STORAGE SILO
FLYASH FEED BIN
FEEDER (TYP)
WEIGH FEEDER
7
FILTER
6
CONVEYORS
MIXER
VACUUM PUMP
FILTRATE RECEIVER
PUMP
BUILDING
CONVEYORS
8
LOADING PILE

STREAM NO	1	2	3	4	5	6	7	8
DESCRIPTION	SLURRY TO FEED TANK	SLURRY TO THICKENER	RECYCLE WATER TO ABSORBER	UNDERFLOW TO FILTER	RECYCLE H_2O FROM FILTER	FILTER CAKE TO MIXER	FLYASH TO MIXER	MATERIAL TO DISPOSAL
LB/HR	409,480	409,480	233,989	175,491	73,121	102,370	54,407	156,777
GPM	742	745	468	277	146	131		
SP GR	110	110	100	127	10	156	200	160
UNDSLVD SLDS %	15	15	0	35	0	60		74

Figure 1. Sludge - flyash blending. Flow diagram and material balance.

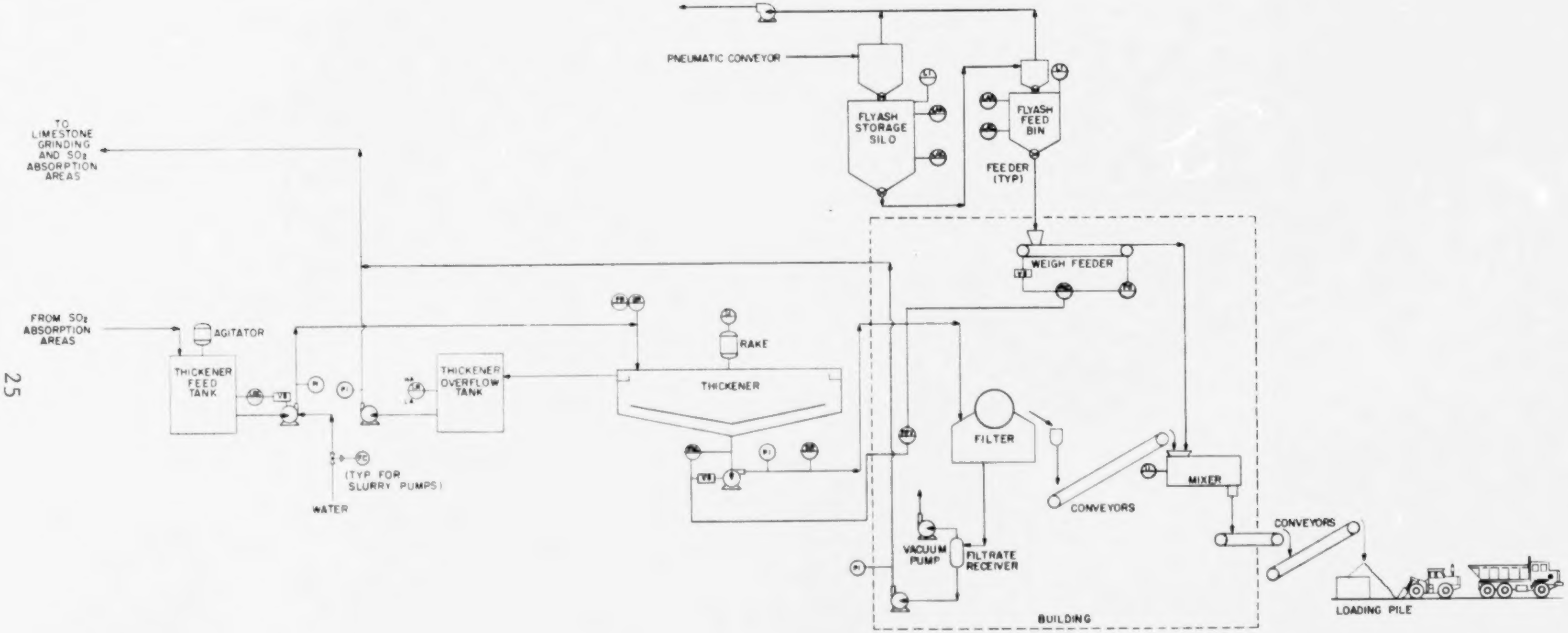

PNEUMATIC CONVEYOR
FLYASH STORAGE SILO
FLYASH FEED BIN
FEEDER (TYP)
TO LIMESTONE GRINDING AND SO_2 ABSORPTION AREAS
FROM SO_2 ABSORPTION AREAS
AGITATOR
THICKENER FEED TANK
THICKENER OVERFLOW TANK
(TYP FOR SLURRY PUMPS)
WATER
RAKE
THICKENER
WEIGH FEEDER
FILTER
CONVEYORS
MIXER
VACUUM PUMP
FILTRATE RECEIVER
BUILDING
CONVEYORS
LOADING PILE

Figure 2. Sludge - flyash blending. Control diagram.

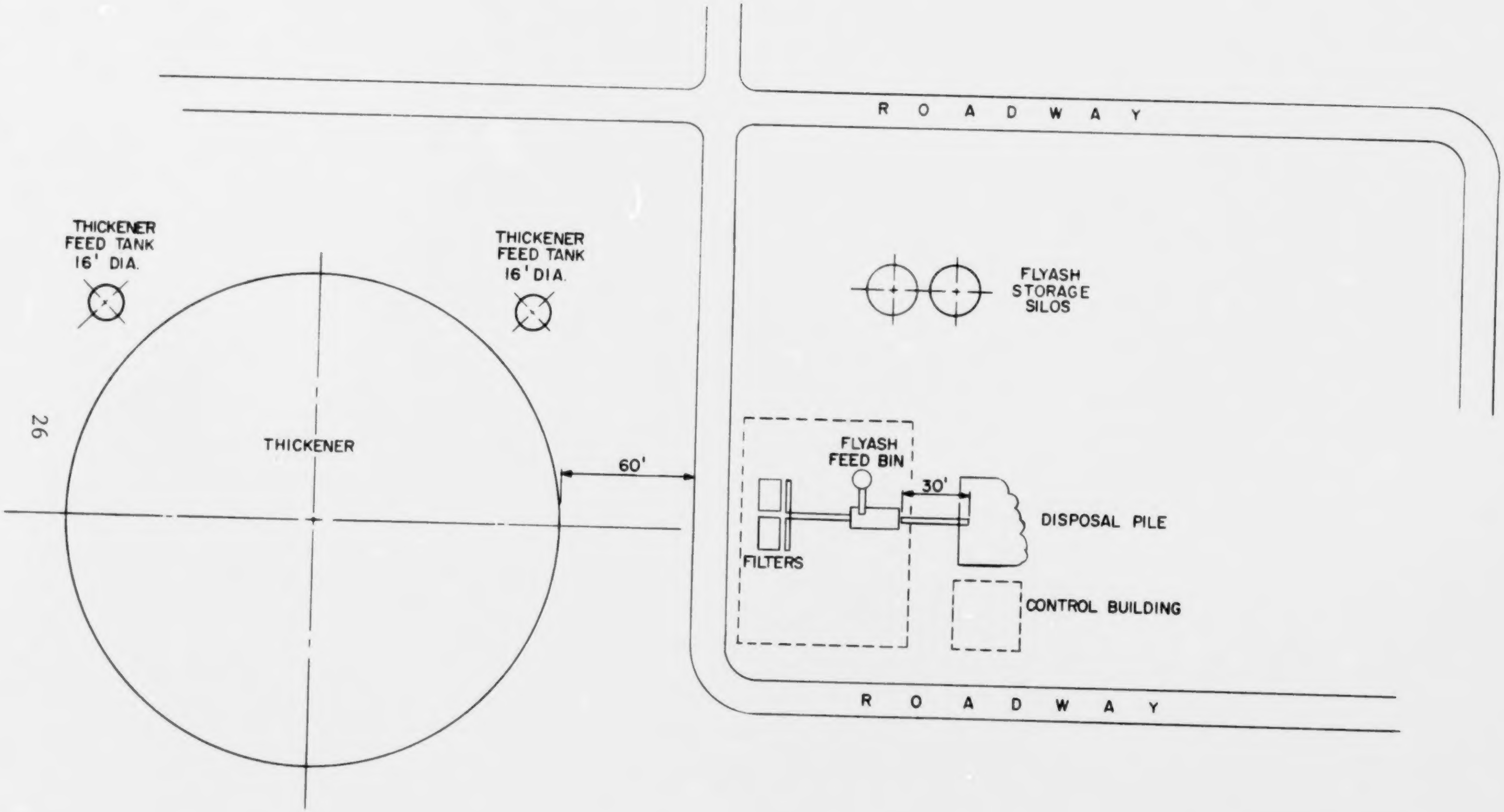

THICKENER FEED TANK 16' DIA.
THICKENER FEED TANK 16' DIA.
THICKENER
60'
ROADWAY
FLYASH STORAGE SILOS
FLYASH FEED BIN
30'
DISPOSAL PILE
FILTERS
CONTROL BUILDING
ROADWAY

Figure 3. Sludge - flyash blending. Plant layout.

TABLE 8. SLUDGE - FLYASH BLENDING

BASE-CASE EQUIPMENT LIST

Item	No.	Description
Pneumatic conveying system, flyash	1	Complete system with blower, cyclone receiver, receiver filter, motor
Storage silo, flyash	2	81,611 ft^3, 1,633 tons, field erected, 41 ft diameter, 62 ft high, carbon steel, with top, 60-degree cone bottom
Feeder, discharge	2	Rotary air lock type, 4,633 lb/hr, 8 in. diameter, 8 in. long, carbon steel
Vibrator, flyash storage silo	16	Electromechanical, rotary vibrators, 1-hp motor
Feed bin, flyash	1	10,881 ft^3, 19 ft diameter, 38 ft high, with top, 60-degree cone bottom, carbon steel
Feeder, bin discharge	1	Rotary air lock type, 8 in. diameter, 8 in. long, carbon steel
Vibrator, flyash feed bin	8	Electromechanical, rotary vibrators, 1-hp motor
Weigh feeder, flyash	1	5 ft long, 14-in. belt, 3-hp D.C. motor, carbon steel
Tank, thickener feed	1	33,525 gal, field erected, 18 ft diameter, 18 ft high, open top, carbon steel, rubber lined with four 1 ft 6 in. x 18 ft baffles offset 3-1/2 in. from wall
Agitator, thickener feed tank	1	25 hp, 72-in. diameter blade, rubber coated
Pump, thickener feed	2	745 gpm, 75-ft head, rubber lined, 40-hp motor
Thickener	1	160-ft diameter, stainless steel- or rubber-lined concrete basin with rake and motor (1 spare)
Tank, thickener overflow	1	8,310 gal, 12 ft diameter, 12 ft high, carbon steel, rubber lined, with flat bottom
Pump, thickener overflow recycle	2	468 gpm, 75-ft head, rubber lined, 20-hp motor
Pump, thickener underflow to filter	2	277 gpm, 75-ft head, rubber lined, 15-hp motor
Sump pump, thickener tunnel	1	5 gpm, 10-ft head, carbon steel, 1/4-hp motor
Rotary drum filter	2	500 ft^2 surface area, 12 ft diameter, 14-ft long drum, stainless steel (wetted parts), vacuum and filtrate pumps included
Pump, filtrate recycle	2	146 gpm, 75-ft head, rubber lined, 15-hp motor
Conveyor, horizontal belt	2	52 tons/hr, 16 ft long, 18-in. belt, 100 ft/min, 1/2-hp motor
Conveyor, sloping belt	1	52 tons/hr, 30 ft long, 18-in. belt, 100 ft/min, 1/2-hp motor
Mixer	2	Carbon steel, 30-hp motor
Conveyor, sloping belt	1	79 tons/hr, 30 ft long, 24-in. belt, 100 ft/min, 1/2-hp motor

Field Equipment

With the exception of buildings, the description of field equipment for the sludge - flyash blending process also pertains to this process. For this process two builindgs are required. The control-room building is 30 feet wide by 30 feet long by 12 feet high. The equipment building is 40 feet wide by 50 feet long by 30 feet high for the 200- and 500-MW plants. For the 1500-MW plants it is 40 feet wide by 100 feet long by 30 feet high.

A flow diagram and material balance is shown in Figure 4. Figures 5 and 6 show the control diagram and layout. Major process equipment items are listed in Table 9.

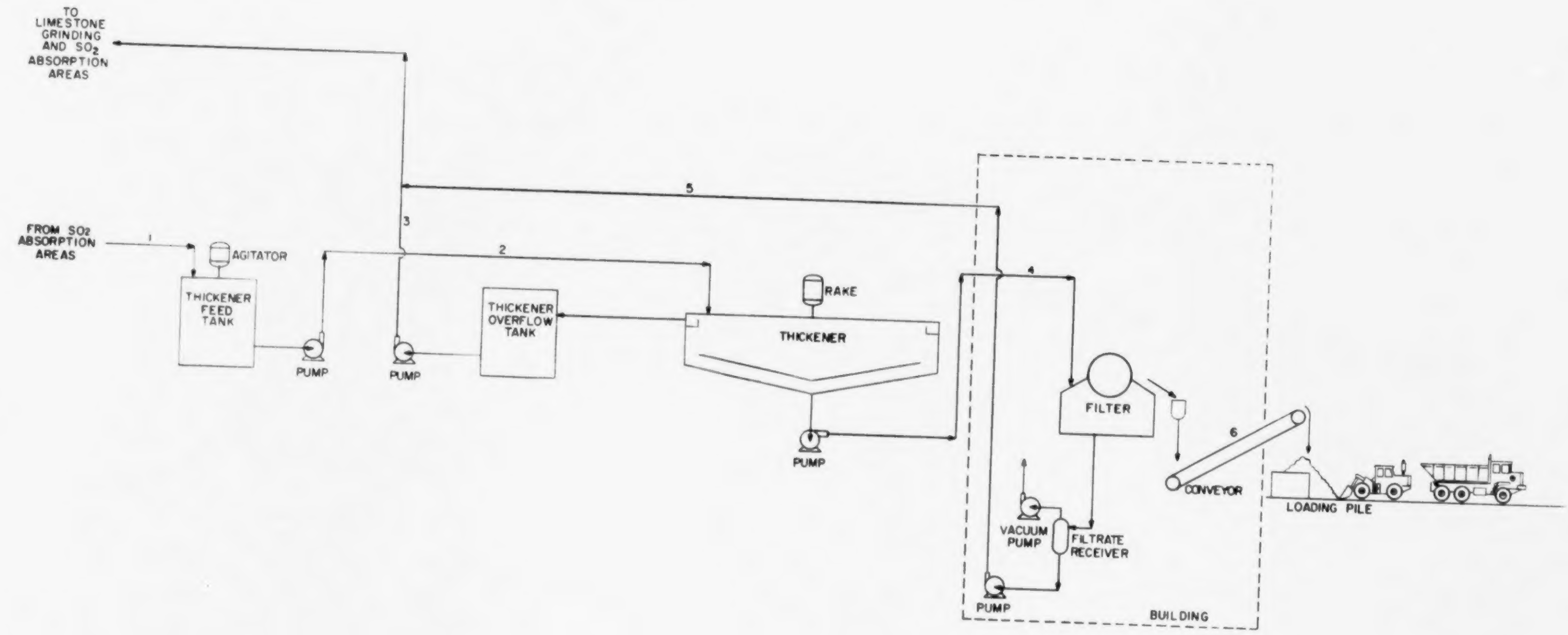
WASTE MATERIAL AND DISPOSAL

Each estimate is directly affected by the quantity of material that must be handled. Table 10 lists the cases considered in this study and the quantity of material for disposal. The final solids content of the sludge - flyash blending process varies with the fuel composition and stoichiometry used. The base-case waste is 74% solids. The solids for fuel and stoichiometry case variations range from 71% to 82%. No bulk density adjustments were made for these relatively minor changes.

The waste in the disposal pile is loaded onto dump trucks with a wheeled front-end loader, hauled to the disposal site over hard-surfaced roadways, and dumped on a prepared section of the site cleared, stripped of topsoil, and suitably contoured. The dumped waste is shaped and compacted to form a 30-foot waste depth using graders, dozers, and rollers. The site is filled in successive sections prepared as required. A 2-foot-thick layer of compacted and contoured soil obtained from the site is placed over the waste when it is emplaced to the full depth. In addition to waste emplacement, the equipment and personnel are used to maintain the site during use of the site for disposal. A watering truck is provided to control dusting.

The size of the site is based on the volume of waste generated during the life of the power plant. For the base-case conditions the following equipment is required:

	Sludge - flyash blending		Gypsum	
Mobile equipment	No.	Size	No.	Size
Wheeled front-end loader	1 + 1 spare	2.75 yd^3	1 + 1 spare	2.75 yd^3
Trucks	2 + 1 spare	10 yd^3	2 + 1 spare	8 yd^3
Grader	1	-	1	-
Dozer	1	-	1	-
Compactor	1	-	1	-
Pickup truck	1	-	-	-
Water tanker	1	-	1	6,000 gal


TO LIMESTONE GRINDING AND SO2 ABSORPTION AREAS
FROM SO2 ABSORPTION AREAS
1
AGITATOR
THICKENER FEED TANK
PUMP
2
3
PUMP
THICKENER OVERFLOW TANK
5
RAKE
THICKENER
PUMP
4
FILTER
6
CONVEYOR
LOADING PILE
VACUUM PUMP
FILTRATE RECEIVER
PUMP
BUILDING

STREAM NO	1	2	3	4	5	6
DESCRIPTION	SLURRY TO THICKENER FEED TANK	SLURRY TO THICKENER	THICKENER OVERFLOW	UNDERFLOW TO THICKENER	RECYCLE FILTRATE	FILTER CAKE TO DISPOSAL
LB/HR	755,880	755,880	431,931	323,949	182,221	141,728
GPM	1274	1274	804	510	304	146
SP. GR.	1.10	1.10	1.0	1.27	1.0	1.94
UND SLVD SLDS. %	15	15	0	35	0	80

Figure 4. Gypsum. Flow diagram and material balance.

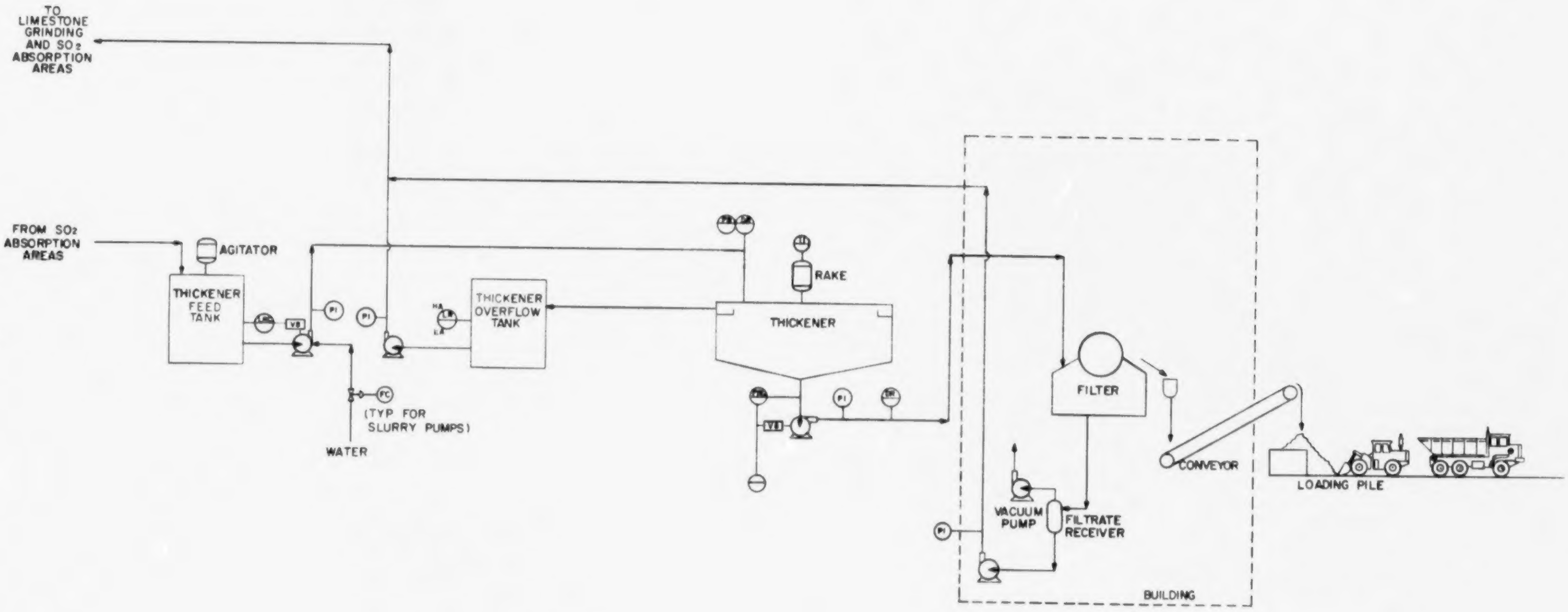

TO LIMESTONE GRINDING AND SO₂ ABSORPTION AREAS
FROM SO₂ ABSORPTION AREAS
AGITATOR
THICKENER FEED TANK
VS
PI
PI
HA
LA
THICKENER OVERFLOW TANK
FC
(TYP FOR SLURRY PUMPS)
WATER
RAKE
THICKENER
VS
PI
FILTER
VACUUM PUMP
FILTRATE RECEIVER
PI
CONVEYOR
LOADING PILE
BUILDING

Figure 5. Gypsum. Control diagram.

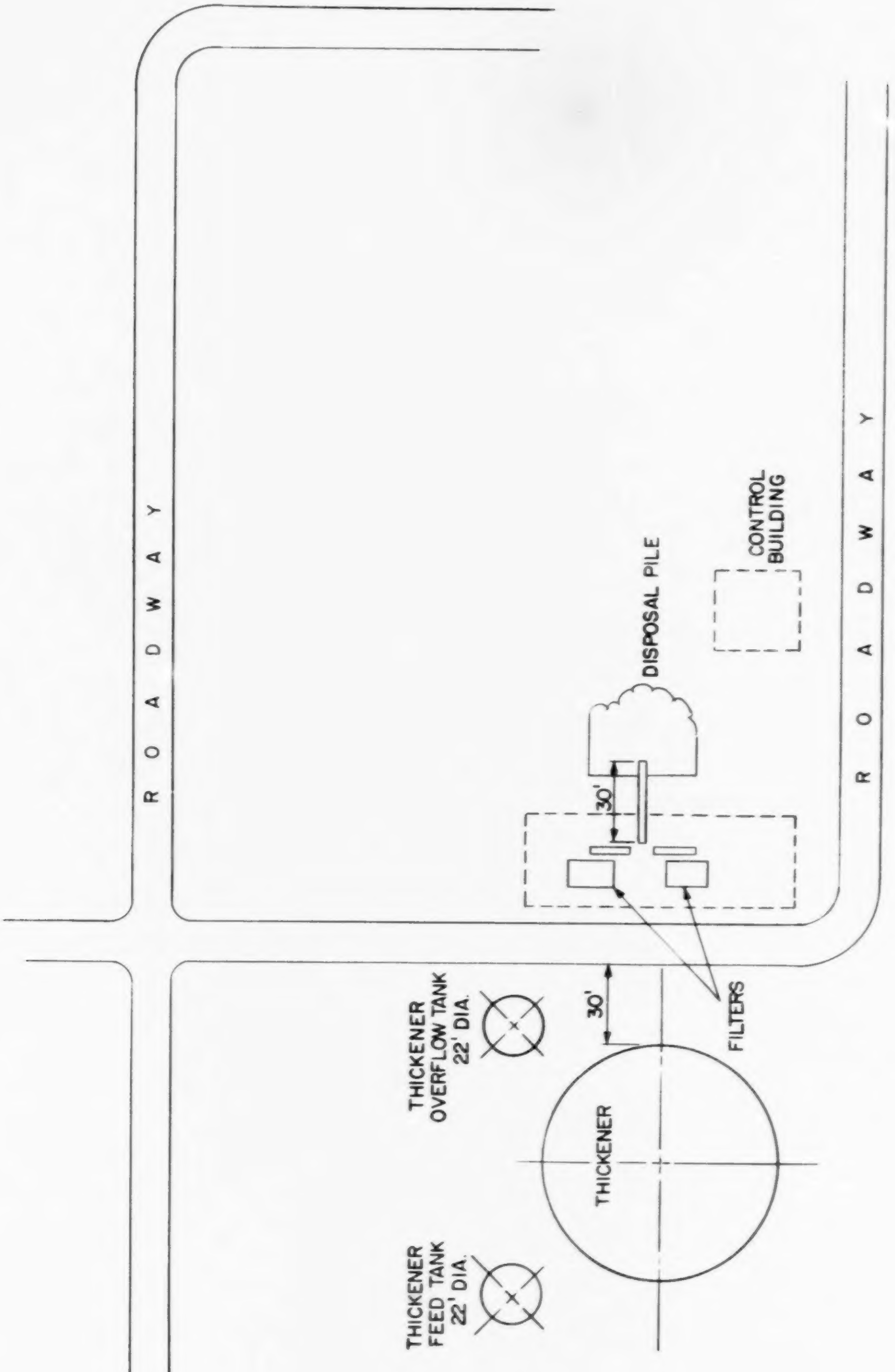

ROADWAY
ROADWAY
DISPOSAL PILE
CONTROL BUILDING
30'
FILTERS
THICKENER OVERFLOW TANK 22' DIA.
30'
THICKENER
THICKENER FEED TANK 22' DIA.

Figure 6. Gypsum. Layout drawing.

TABLE 9. GYPSUM - BASE-CASE EQUIPMENT LIST

Item	No.	Description
Tank, thickener feed	1	62,000 gal, field erected, 22 ft diameter, 22 ft high, open top, carbon steel, rubber lined with four 22 in. x 22 ft baffles offset 3-1/2 in. from wall
Agitator, thickener feed tank	1	30 hp, 84 in. diameter, rubber coated
Pump, thickener feed	2	1374 gpm, 75-ft head, rubber lined, 60-hp motor
Thickener	1	82 ft diameter, stainless steel- or rubber-lined concrete basin with rake and motor (1 spare)
Tank, thickener overflow	1	25,920 gal, 21 ft diameter, 10 ft high, carbon steel, rubber lined with flat bottom
Pump, thickener overflow recycle	2	864 gpm, 75-ft head, rubber lined, 30-hp motor
Pump, thickener underflow to filter	2	510 gpm, 75-ft head, rubber lined, 25-hp motor
Sump pump, thickener tunnel	1	5 gpm, 10-ft head, carbon steel, 1/4-hp motor
Rotary drum filter	3	500 ft^2 surface area, 12 ft diameter, 14-ft-long drum, stainless steel (wetted parts), vacuum and receiver pumps included
Pump, filtrate recycle	1	364 gpm, 75-ft head, rubber lined, 15-hp motor
Conveyor, horizontal belt	3	71 tons/hr, 16 ft long, 16-in. belt, 100 ft/min, 1/2-hp motor
Conveyor, sloping belt	1	71 tons/hr, 30 ft long, 30-in. belt, 100 ft/min, 1/2-hp motor

TABLE 10. QUANTITIES OF SLUDGE FOR DISPOSAL - ALL CASE VARIATIONS

Case	Amount of waste for disposal, lb/hr	
	Sludge - flyash blending[a]	Gypsum[b]
Base case[c]	156,777[d]	141,728[e]
Variation from base case		
200 MW	64,107	57,953
1500 MW	470,328	425,195
Existing, 25-yr remaining life	160,264	144,879
Existing, 20-yr remaining life	160,264	144,879
Existing, 15-yr remaining life	160,264	144,879
2% S in coal	98,615	99,296
5% S in coal	214,433	179,945
12% ash in coal	133,832	116,758
20% ash in coal	182,494	169,715
Lime scrubbing process	131,767	136,628
5 mi to disposal	156,777	141,728
10 mi to disposal	156,777	141,728
7000 hr/yr operating profile	156,777	141,728
200 MW, 7000 hr/yr operating profile	64,107	57,953
1500 MW, 7000 hr/yr operating profile	470,328	425,195
Sludge - flyash layering	156,777	-
1.3 limestone stoichiometry	145,632	-

a. Landfill disposal of blended 60% solids sludge and dry ESP-collected flyash at a bulk density of 97 lb/ft^3.

b. Landfill disposal of 80% solids gypsum at 121 lb/ft^3; flyash collected in scrubber and disposed of with gypsum.

c. New 500-MW plant; 30-year life; coal analysis (by wt) - 3.5% S (dry), 16% ash; limestone scrubbing process; declining operating profile (first year) 7,000 hours.

d. Waste is 27% sulfur salts, 12% limestone solids, 35% flyash, 26% water.

e. Waste is 38% sulfur salts, 3% limestone solids, 39% flyash, 20% water.

RESULTS

Capital investment and annual revenue requirement estimates for the base cases and each case variation are shown in Appendix A. A summary of the capital investment for each case of the sludge - flyash blending process is shown in Table 11. Annual revenue requirements for the process are summarized in Table 12. Capital investment for each case of the gypsum process is summarized in Table 13. Annual revenue requirements for each case of the process are summarized in Table 14.

The estimates shown in Appendix A and tables in the text do not include costs associated with ESP collection of flyash or scrubber modifications for air oxidation to gypsum. Additional capital investment for base-case ESP collection of flyash is \$9,614,000 and annual revenue requirements are \$1,975,000. Additional capital investment for base-case air oxidation is \$2,303,000 and annual revenue requirements are \$1,005,000 for the base-case gypsum process. These costs can be included with the disposal system costs in making comparisons with systems which do not have separate flyash removal or air-oxidation equipment. For determination of overall scrubbing and disposal costs a base-case limestone scrubber capital investment of \$36,368,000 and annual revenue requirements of \$11,842,000 (22) can be combined with the appropriate flyash-collection or air-oxidation and disposal costs.

BASE CASE

Capital investment for the base-case sludge - flyash blending process is \$8,605,000, equivalent to 17.2 \$/kW. Including flyash collection the capital investment is \$18,219,000, or 36.4 \$/kW. Direct investment, excluding flyash collection and waste transportation and disposal, is 39% of the total. Mobile equipment costs, consisting of trucks, loaders, and earthmoving equipment, is 7% and land purchase is 6% of the total.

Capital investment for the base-case gypsum process is \$5,411,000, or 10.8 \$/kW. Including scrubber modifications for air oxidation the capital investment is \$7,714,000, or 15.4 \$/kW. Direct investment, excluding air-oxidation scrubber modifications and waste transportation and disposal, is 35% of the total capital investment. Mobile equipment cost is 9% and land is 7% of the total.

Annual revenue requirements for the base-case conditions are \$3,772,600, or 1.08 mills/kW, for the sludge - flyash blending process

TABLE 11. TOTAL CAPITAL INVESTMENT SUMMARY - SLUDGE - FLYASH BLENDING

Case	Total capital investment, k$	$/kW
Base case	8,605	17.2
Variation from base case		
200 MW	6,126	30.6
1500 MW	18,282	12.2
Existing, 25-yr remaining life	8,528	17.1
Existing, 20-yr remaining life	8,381	16.8
Existing, 15-yr remaining life	8,276	16.6
2% S in coal	7,356	14.7
5% S in coal	10,073	20.1
12% ash in coal	7,917	15.8
20% ash in coal	9,309	18.6
Lime scrubbing process	8,178	16.4
5 mi to disposal	8,969	17.9
10 mi to disposal	9,334	18.7
7000 hr/yr operating profile	8,955	17.9
200 MW, 7000 hr/yr operating profile	6,268	31.3
1500 MW, 7000 hr/yr operating profile	19,321	12.9
Sludge - flyash layering	8,743	17.5
1.3 stoichiometry	8,160	16.3

Basis: Midwest plant location; average basis for cost scaling, mid-1979. SO_2 and flyash removed to meet NSPS.

Base case: New 500-MW plant with 30-yr life; landfill disposal of dewatered sulfite sludge and dry flyash blends 1 mi from the scrubber facilities.

TABLE 12. SUMMARY OF REVENUE REQUIREMENTS - SLUDGE - FLYASH BLENDING

Case	Total annual amount, k$	Unit revenue requirement Mills/kWh	$/ton dry sludge	$/ton wet sludge
Base case	3,773	1.08	9.29	6.87
Variation from base case				
200 MW	2,779	1.99	16.73	12.39
1500 MW	6,922	0.66	5.69	4.20
Existing, 25-yr remaining life	3,852	1.10	9.28	6.87
Existing, 20-yr remaining life	3,876	1.10	9.34	6.91
Existing, 15-yr remaining life	3,982	1.14	9.59	7.10
2% S in coal	3,224	0.92	11.40	9.34
5% S in coal	4,282	1.22	8.03	5.71
12% ash in coal	3,617	1.03	10.88	7.72
20% ash in coal	3,965	1.13	8.17	6.21
Lime scrubbing process	3,650	1.04	10.28	7.91
5 mi to disposal	4,425	1.26	10.90	8.07
10 mi to disposal	4,891	1.40	12.05	8.92
7000 hr/yr operating profile	3,801	1.09	9.76	6.93
200 MW, 7000 hr/yr operating profile	2,791	2.00	16.80	12.44
1500 MW, 7000 hr/yr operating profile	7,012	0.67	5.76	4.25
Sludge - flyash layering	3,866	1.10	9.54	7.05
1.3 stoichiometry	3,673	1.04	9.73	7.19

Basis: Midwest plant location, mid-1980 costs; 7000 hr/yr on-stream time, SO_2 and flyash removed to meet NSPS.

Base case: New 500-MW plant with 30-yr life; landfill disposal of 75% solids, sludge and flyash blending; 1 mi to disposal site from scrubber facilities; transport by truck to disposal area.

TABLE 13. TOTAL CAPITAL INVESTMENT SUMMARY - GYPSUM

Case	Total capital investment, k$	$/kW
Base case	5,411	10.8
Variation from base case		
200 MW	3,964	19.8
1500 MW	9,826	6.6
Existing, 25-yr remaining life	5,174	10.3
Existing, 20-yr remaining life	5,115	10.2
Existing, 15-yr remaining life	5,076	10.2
2% S in coal	4,782	9.6
5% S in coal	5,884	11.8
12% ash in coal	5,042	10.1
20% ash in coal	5,707	11.4
Lime scrubbing process	5,315	10.6
5 mi to disposal	5,750	11.5
10 mi to disposal	6,005	12.0
7000 hr/yr operating profile	5,672	11.3
200 MW, 7000 hr/yr operating profile	4,093	20.5
1500 MW, 7000 hr/yr operating profile	10,603	7.1

Basis: Midwest plant location; average basis for cost scaling, mid-1979. SO_2 and flyash removed to meet NSPS. Base case: New 500-MW plant with 30-yr life; landfill disposal of dewatered (80% solids) gypsum 1 mi from scrubber facilities.

TABLE 14. SUMMARY OF REVENUE REQUIREMENTS - GYPSUM

Case	Total annual amount, k$	Unit revenue requirement		
		Mills/kWh	$/ton dry sludge	$/ton wet sludge
Base case	3,118	0.89	7.86	6.28
Variation from base case				
200 MW	2,327	1.66	14.31	11.44
1500 MW	4,961	0.47	4.17	3.33
Existing, 25-yr remaining life	3,143	0.89	7.74	6.20
Existing, 20-yr remaining life	3,160	0.90	7.79	6.24
Existing, 15-yr remaining life	3,227	0.92	7.96	6.37
2% S in coal	2,707	0.77	9.74	7.79
5% S in coal	3,252	0.93	6.45	5.16
12% ash in coal	3,018	0.86	9.23	7.39
20% ash in coal	3,206	0.92	6.75	5.40
Lime scrubbing process	3,104	0.89	8.11	6.49
5 mi to disposal	3,694	1.05	9.31	7.45
10 mi to disposal	4,286	1.22	10.80	8.64
7000 hr/yr operating profile	3,146	0.90	7.93	6.34
200 MW, 7000 hr/yr operating profile	2,401	1.72	14.75	11.79
1500 MW, 7000 hr/yr operating profile	5,028	0.48	4.23	3.37

Basis: Midwest plant location; mid-1980 costs; 7000 hr/yr on-stream time, SO_2 and flyash removed to meet NSPS.

Base case: New plant with 30-yr life; landfill disposal of 80% solids material; 1 mi to disposal site from scrubber facilities; transport by truck to the disposal area.

and \$3,117,500, or 0.89 mill/kWh, for the gypsum process. Including the additional annual costs of \$1,975,000, for separate flyash removal, the annual revenue requirements for the sludge - flyash blending process are \$5,747,000, or 1.64 mills/kWh. Including the additional annual costs of \$1,005,000 for air oxidation, the annual revenue requirements for the gypsum process are \$4,122,500, or 1.18 mills/kWh.

In terms of quantity of waste, the sludge - flyash blending process revenue requirements are 6.9 \$/ton of wet waste and 9.3 \$/ton of dry solids. Including ESP operation the costs are 10.5 \$/ton of wet waste and 14.2 \$/ton of dry solids. The gypsum process annual revenue requirements are 6.3 \$/ton of wet waste and 7.9 \$/ton of dry solids without air-oxidation costs and 8.3 \$/ton of wet waste and 10.4 \$/ton of dry solids with air-oxidation costs included.

Operating labor and supervision is the major direct cost of both processes. Plant labor and supervision cost is 12% and landfill labor and supervision cost is 20% of the annual revenue requirements of the sludge - flyash blending process and 14% and 24% of the requirements of the gypsum process. Landfill costs for land preparation, fuel, and maintenance are \$129,000, or 0.04 mill/kWh, for the sludge - flyash blending process and \$116,000, or 0.03 mill/kWh, for the gypsum process, a minor portion of the annual revenue requirements in both cases. Energy costs are also a minor part of the annual revenue requirements of both processes.

Tables 15 through 18 show the capital investments and annual revenue requirements in modular form. They are calculated by processing or handling area using the same procedures used for the overall economics. In each area all costs are assigned on the basis of equipment function, building and land requirements, electrical use, and labor requirements.

The modularized results further illustrate the effects of process requirements on costs. The relatively high costs of separate flyash collection and handling account for almost two-thirds of the sludge - flyash blending capital investment costs. In comparison air-oxidation modifications are only one-fourth of the gypsum process capital investment. Other than flyash collection and handling and air-oxidation modifications, thickening costs are the major capital investment cost. Filtration and disposal costs are also significant elements in capital investment costs. Mixing contributes relatively little to capital investment costs.

Flyash collection and handling is also the largest element of the sludge - flyash blending process annual revenue requirements, contributing about 45% of the total. Air-oxidation costs are about 25% of the gypsum process annual revenue requirements. In contrast to the relatively low capital investment, disposal costs are a large part of annual revenue requirements for both processes. Dewatering and mixing annual revenue requirements are significant but not major cost elements.

TABLE 15. MODULAR CAPITAL INVESTMENT - BASE-CASE SLUDGE - FLYASH BLENDING

	Costs by area, k$						
	ESP costs	Flyash handling	Thickening	Filtration	Mixing	Disposal	Total
Process equipment		495	1,101	333	56		1,985
Piping and insulation		53	47	24	15		139
Foundation and structural		92	82	41	27		242
Excavation and site preparation		20	18	9	6		53
Electrical		159	59	79	48		345
Instrumentation		21	19	10	6		56
Buildings		192	171	86	55		504
Subtotal		1,032	1,497	582	213		3,324
Services and miscellaneous		19	17	9	5		50
Subtotal		1,051	1,514	591	218		3,374
Mobile equipment						581	581
Subtotal direct investment		1,051	1,514	591	218	581	3,955
Engineering design and supervision		104	150	59	21		334
Architect and engineering		26	38	14	5		83
Construction expense		214	308	120	44		686
Contractor fees		85	122	48	18		273
Subtotal		1,480	2,132	832	306	581	5,331
Contingency		283	408	159	59	157	1,066
Subtotal fixed investment		1,763	2,540	991	365	738	6,397
Allowance for startup		182	261	102	37		582
Interest during construction		205	294	114	42	113	768
Subtotal capital investment		2,150	3,095	1,207	444	851	7,747
Land		5	5	2	2	522	536
Working capital		86	123	48	18	47	322
Total capital investment	9,614	2,241	3,223	1,257	464	1,420	18,219
$/kW	19.2	4.5	6.5	2.5	0.9	2.8	36.4

TABLE 16. MODULAR ANNUAL REVENUE REQUIREMENTS - BASE-CASE SLUDGE - FLYASH BLENDING

	Costs by area, k$						
	ESP costs	Flyash handling	Thickening	Filtration	Mixing	Disposal	Total
Direct Costs							
Conversion costs							
Operating labor							
Plant		166	149	75	48		438
Solids disposal						745	745
Process maintenance		60	54	27	17		158
Landfill operation							
Land preparation						9	9
Trucks						33	33
Earthmoving equipment						88	88
Electricity		35	13	18	10		77
Analyses		6	6	3	2		17
Subtotal direct costs		267	222	123	77	875	1,564
Indirect Costs							
Capital charges							
Depreciation, interim replacement, and insurance		168	242	95	35	67	607
Cost of capital and taxes		193	277	108	40	122	740
Plant overhead		116	104	52	34	437	744
Administrative overhead		17	15	7	5	75	118
Subtotal indirect costs		494	638	262	114	701	2,209
Total annual revenue requirements	1,975	761	860	385	191	1,576	5,748
Mills/kWh	0.56	0.22	0.25	0.11	0.05	0.45	1.64

TABLE 17. MODULAR CAPITAL INVESTMENT - BASE-CASE GYPSUM

	Costs by area, k$				
	Scrubber modifications	Thickening	Filtration	Disposal	Total
Process equipment		686	493		1,179
Piping and insulation		117	57		174
Foundation and structural		17	8		25
Excavation and site preparation		28	14		42
Electrical		147	73		220
Instrumentation		35	17		52
Buildings		117	57		174
Subtotal		1,147	719		1,866
Services and miscellaneous		18	9		27
Subtotal		1,165	728		1,893
Mobile equipment				498	498
Subtotal direct investment		1,165	728	498	2,391
Engineering design and supervision		131	64		195
Architect and engineering		32	16		48
Construction expense		285	140		425
Contractor fees		125	61		186
Subtotal		1,738	1,009	498	3,245
Contingency		348	202	99	649
Subtotal fixed investment		2,086	1,211	597	3,894
Allowance for startup		228	112		340
Interest during construction		250	145	72	467
Subtotal capital investment		2,564	1,468	669	4,701
Land		8	4	391	403
Working capital		150	93	64	307
Total capital investment	2,303	2,722	1,565	1,124	7,714
$/kW	4.6	5.4	3.1	2.3	15.4

TABLE 18. MODULAR ANNUAL REVENUE REQUIREMENTS - BASE-CASE GYPSUM

	Costs by area, k$				
	Air oxidation modifications	Thickening	Filtration	Disposal	Total
Direct Costs					
Conversion costs					
Operating labor					
Plant		294	144		438
Solids disposal				745	745
Process maintenance		64	32		96
Landfill operation					
Land preparation				7	7
Trucks				30	30
Earthmoving equipment				79	79
Electricity		20	28		48
Analyses		11	6		17
Subtotal direct costs		389	210	861	1,460
Indirect Costs					
Capital charges					
Depreciation, interim replacement, and insurance		201	115	52	368
Cost of capital and taxes		234	135	96	465
Plant overhead		185	91	430	706
Administrative overhead		29	14	75	118
Subtotal indirect costs		649	355	653	1,657
Total annual revenue requirements	1,005	1,038	565	1,514	4,122
Mills/kWh	0.29	0.30	0.16	0.43	1.18

CASE VARIATIONS

Case variations for both processes were calculated to define cost sensitivities to power plant size using both the declining-load and constant-load operating schedules, power plant age, coal sulfur content, coal ash content, distance to disposal site, and lime instead of limestone scrubbing. The sludge - flyash blending process was also evaluated using two additional case variations of limestone stoichiometry and disposal of dewatered sludge and flyash in unblended alternate layers.

In addition to first-year annual revenue requirements, lifetime revenue requirements were determined for both processes using three power plant sizes and both the declining-load and constant-load schedules.

Power Plant Size and Operating Schedule

Declining-Load Operating Schedule--

In addition to the 500-MW base-case condition, estimates were made for 200- and 1500-MW power plants using the same conditions as were used for the base case. Capital investments and annual revenue requirements for the sludge - flyash blending processes are shown in Tables 19 and 20, and for the gypsum processes in Tables 21 and 22. The same data are summarized graphically in Figures 7-12, illustrating the decrease in disposal costs with increase in plant size. Capital investment for the sludge - flyash blending process increases only 40% from the 200-MW to the 500-MW plant sizes and 158% from the 200-MW to the 1500-MW plant sizes, compared to power output increases of 150% and 650%. For the gypsum process the capital investment increases only 37% and 148% for the same power output increases. Most of the differences in capital cost between the power plant sizes are a result of lower process equipment costs and mobile equipment costs relative to units of power output. Land costs, which are directly related to the quantity of waste produced, increase in proportion to power plant size.

Annual revenue requirements show the same disproportionately smaller increases in relation to power plant size. In this case the cause is smaller increases in operating labor and supervision for both plant and disposal equipment, relative to power plant size. Landfill costs, which are directly related to quantity of waste, increase in proportion to power plant size.

Constant-Load Operating Schedule--

Estimates were also made for the three power plant sizes using a constant-load operating schedule of 7000 hr/yr for the 30-year life of the power plant. The effect of this variation, resulting in a total operating lifetime of 210,000 hours instead of the 127,500 hours of the base-case declining-load operating schedule, is to increase land requirements for waste disposal, resulting in the increases in capital investment. Similarly, the only change in first-year annual revenue requirements is to increase the costs of capital and taxes which are based on

TABLE 19. CAPITAL INVESTMENT ANALYSIS - SLUDGE - FLYASH BLENDING

	Capital investment[a]					
	200 MW		500 MW		1500 MW	
	k$	Percent of total	k$	Percent of total	k$	Percent of total
Process equipment	1,211	19.8	1,985	23.1	4,152	22.7
Piping and insulation	117	1.9	139	1.6	214	1.2
Foundation and structural	122	2.0	242	2.8	1,264	6.9
Excavation, site preparation, roads and railroads	44	0.8	53	0.6	85	0.5
Electrical	284	4.6	345	4.0	540	3.0
Instrumentation	52	0.8	56	0.7	80	0.4
Buildings	504	8.2	504	5.8	954	5.2
Subtotal	2,334	38.1	3,324	38.6	7,289	39.9
Services and miscellaneous	35	0.6	50	0.6	109	0.6
Subtotal excluding trucks and earthmoving equipment	2,369	38.7	3,374	39.2	7,398	40.5
Trucks and earthmoving equipment	451	7.3	581	6.8	1,307	7.1
Subtotal direct investment	2,820	46.0	3,955	46.0	8,705	47.6
Engineering design and supervision	288	4.7	334	3.9	472	2.6
Architect-engineering contractor expense	72	1.2	83	0.9	118	0.7
Construction expense	511	8.4	686	8.0	1,316	7.2
Contractor fees	211	3.4	273	3.2	497	2.7
Subtotal	3,902	63.7	5,331	62.0	11,108	60.8
Contingency	780	12.7	1,066	12.3	2,222	12.1
Subtotal fixed investment	4,682	76.4	6,397	74.3	13,330	72.9
Allowance for startup and modification	423	6.9	582	6.8	1,202	6.6
Interest during construction	562	9.2	768	8.9	1,600	8.7
Subtotal capital investment	5,667	92.5	7,747	90.0	16,132	88.2
Land	221	3.6	536	6.3	1,607	8.8
Working capital	238	3.9	322	3.7	543	3.0
Total capital investment	6,126	100.0	8,605	100.0	18,282	100.0

a. Basis

New plant (30-year life), Midwest plant location, mid-1979 costs.
Coal analysis (by wt): 3.5% sulfur (dry basis), 16% ash.
Fly ash and SO_2 removed to meet NSPS.
Limestone process with 1.5 stoichiometry based on SO_2 removed.
Landfill disposal 1 mile from scrubber facilities, trucks used for transport of treated material to disposal site.

TABLE 20. ANNUAL REVENUE REQUIREMENTS - SLUDGE - FLYASH BLENDING

	Annual revenue requirements, $[a]		
	200 MW	500 MW	1500 MW
Direct Costs			
Conversion costs			
Operating labor and supervision			
Plant	328,500	438,000	547,500
Solids disposal equipment	595,700	744,600	1,191,400
Maintenance--plant labor and supervision, 4% of direct investment	112,800	158,200	348,200
Landfill operation			
Land preparation	3,600	8,700	26,000
Trucks (fuel and maintenance)	13,500	32,900	98,800
Earthmoving equipment (fuel and maintenance)	35,900	87,800	263,400
Electricity	55,400	76,900	161,900
Analyses	17,000	17,000	25,500
Subtotal conversion costs	1,162,400	1,564,100	2,662,700
Total direct costs	1,162,400	1,564,100	2,662,700
Indirect Costs			
Capital charges			
Depreciation, interim replacement, and insurance at 7.83% of total capital investment less land and working capital	443,700	606,600	1,263,100
Average cost of capital and taxes at 8.6% of total capital investment	526,800	740,000	1,572,300
Overhead			
Plant, 50% of conversion costs less utilities	553,500	743,600	1,250,400
Administrative, 10% of operating labor	92,400	118,300	173,900
Subtotal indirect costs	1,616,400	2,208,500	4,259,700
Total annual revenue requirement	2,778,800	3,772,600	6,922,400
Equivalent unit revenue requirements			
Mills/kWh	1.99	1.08	0.66
$/wet ton	12.39	6.87	4.20
$/dry ton	16.73	9.29	5.69

[a] Basis
New plant (30-year life), Midwest plant location, mid-1980 costs.
Coal analysis (by wt): 3.5% sulfur (dry basis), 16% ash.
Fly ash and SO_2 removed to meet NSPS.
Limestone process with 1.5 stoichiometry based on SO_2 removed.
Landfill disposal 1 mile from scrubber facilities, trucks used for transport of treated material to disposal site.

TABLE 21. CAPITAL INVESTMENT ANALYSIS - GYPSUM

	Capital investment					
	200 MW		500 MW		1500 MW	
	k$	Percent of total	k$	Percent of total	k$	Percent of total
Process equipment	794	20.1	1,179	21.7	2,215	22.4
Piping and insulation	124	3.1	174	3.2	290	3.0
Foundation and structural	17	0.4	25	0.5	47	0.5
Excavation, site preparation, roads and railroads	38	1.0	42	0.8	59	0.6
Electrical	180	4.5	220	4.1	374	3.8
Instrumentation	44	1.1	52	1.0	55	0.6
Buildings	174	4.4	174	3.2	294	3.0
Subtotal	1,371	34.6	1,866	34.5	3,334	33.9
Services and miscellaneous	20	0.5	27	0.5	50	0.5
Subtotal excluding trucks and earthmoving equipment	1,391	35.1	1,893	35.0	3,384	34.4
Trucks and earthmoving equipment	381	9.6	498	9.2	942	9.5
Subtotal direct investment	1,772	44.7	2,391	44.2	4,326	43.9
Engineering design and supervision	172	4.3	195	3.6	264	2.7
Architect-engineering contractor expense	43	1.1	48	0.9	66	0.7
Construction expense	329	8.4	425	7.9	688	7.0
Contractor fees	148	3.7	186	3.4	292	3.0
Subtotal	2,464	62.2	3,245	60.0	5,636	57.3
Contingency	493	12.4	649	12.0	1,127	11.5
Subtotal fixed investment	2,957	74.6	3,894	72.0	6,763	68.8
Allowance for startup and modification	258	6.5	340	6.3	582	5.9
Interest during construction	355	9.0	467	8.6	812	8.3
Subtotal capital investment	3,570	90.1	4,701	86.9	8,157	83.0
Land	165	4.2	403	7.5	1,201	12.2
Working capital	229	5.7	307	5.6	468	4.8
Total capital investment	3,964	100.0	5,411	100.0	9,826	100.0

a. Basis

New plant (30-year life); Midwest plant location, mid-1979 costs.
Coal analysis (by wt); 3.5% sulfur (dry basis), 16% ash.
Fly ash removed with SO_2 to meet NSPS.
Limestone process with 1.1 stoichiometry based on SO_2 removed.
Landfill disposal of 80% solids material 1 mile from scrubber facilities, trucks used for transport of treated material to disposal site.

TABLE 22. ANNUAL REVENUE REQUIREMENTS - GYPSUM

	Annual revenue requirements, \$[a]		
	200-MW	500-MW	1500-MW
Direct Costs			
Conversion costs			
Operating labor and supervision			
Plant	328,500	438,000	547,500
Solids disposal equipment	595,700	744,600	1,042,400
Maintenance--plant labor and supervision, 4% of direct investment	70,900	95,600	173,000
Landfill operation			
Land preparation	2,700	6,600	19,400
Trucks (fuel and maintenance)	12,200	29,800	89,300
Earthmoving equipment (fuel and maintenance)	32,500	79,400	238,100
Electricity	22,500	49,300	116,300
Analyses	17,000	17,000	25,500
Subtotal conversion costs	1,082,000	1,460,300	2,251,500
Total direct costs	1,082,000	1,460,300	2,251,500
Indirect Costs			
Capital charges			
Depreciation, interim replacement, and insurance at 7.83% of total capital investment less land and working capital	279,500	368,100	638,700
Average cost of capital and taxes at 8.6% of total capital investment	343,000	465,300	845,000
Overhead			
Plant, 50% of conversion costs less utilities	529,800	705,500	1,067,400
Administrative, 10% of operating labor	92,400	118,300	159,000
Subtotal indirect costs	1,244,700	1,657,200	2,710,100
Total annual revenue requirements	2,326,700	3,117,500	4,961,600
Equivalent unit revenue requirements			
Mills/kWh	1.66	0.89	0.47
\$/wet ton	11.44	6.28	3.33
\$/dry ton	14.31	7.86	4.17

a. Basis

New plant (30-year life), Midwest plant location, mid-1980 costs.
Coal analysis (by wt); 3.5% sulfur (dry basis), 16% ash.
Fly ash and SO_2 removed to meet NSPS.
Limestone process with 1.5 stoichiometry based on SO_2 removed.
Landfill disposal 1 mile from scrubber facilities, trucks used for transport of treated material to disposal site.

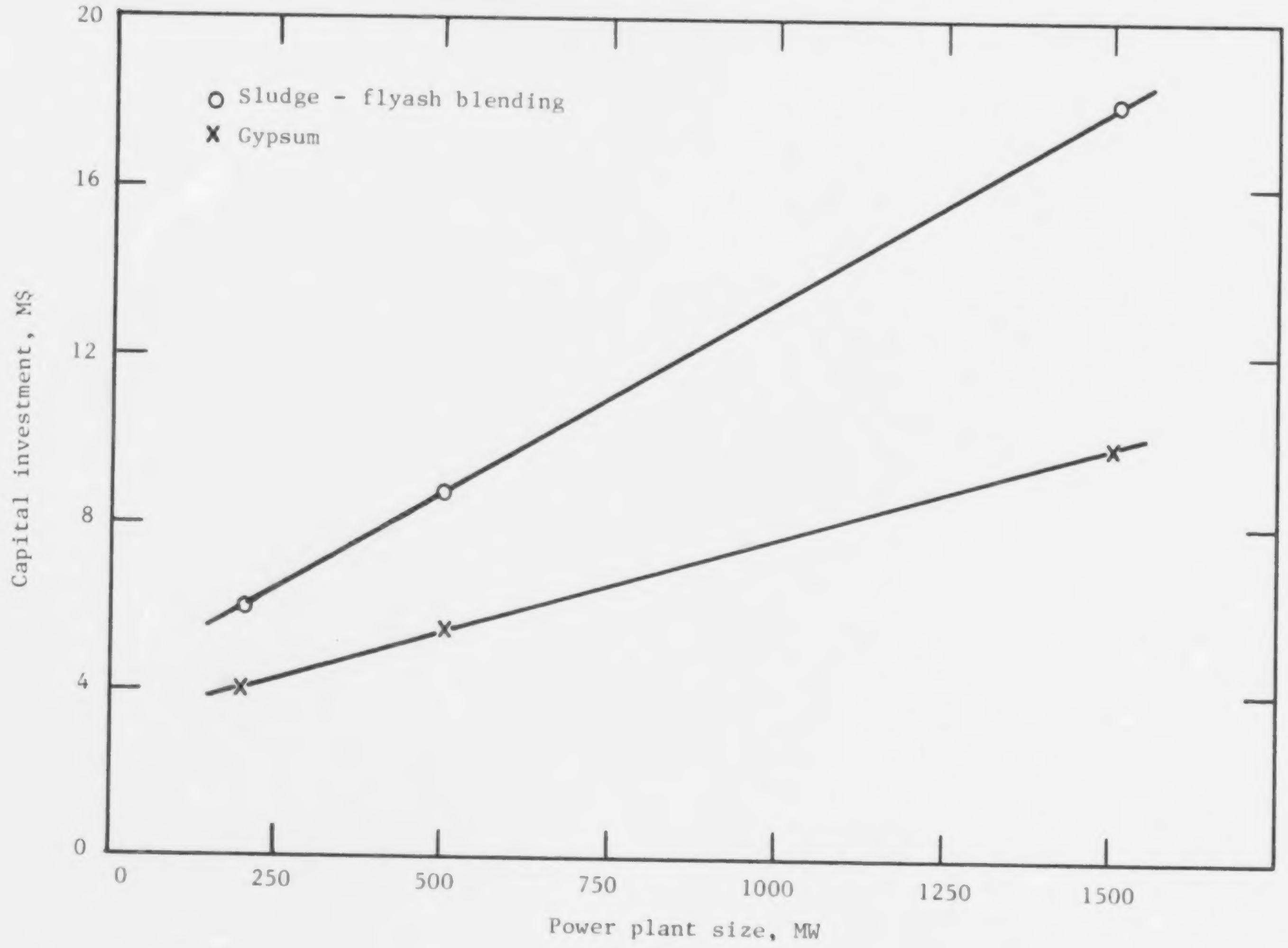


Figure 7. Effect of power plant size on capital investment. New plant.

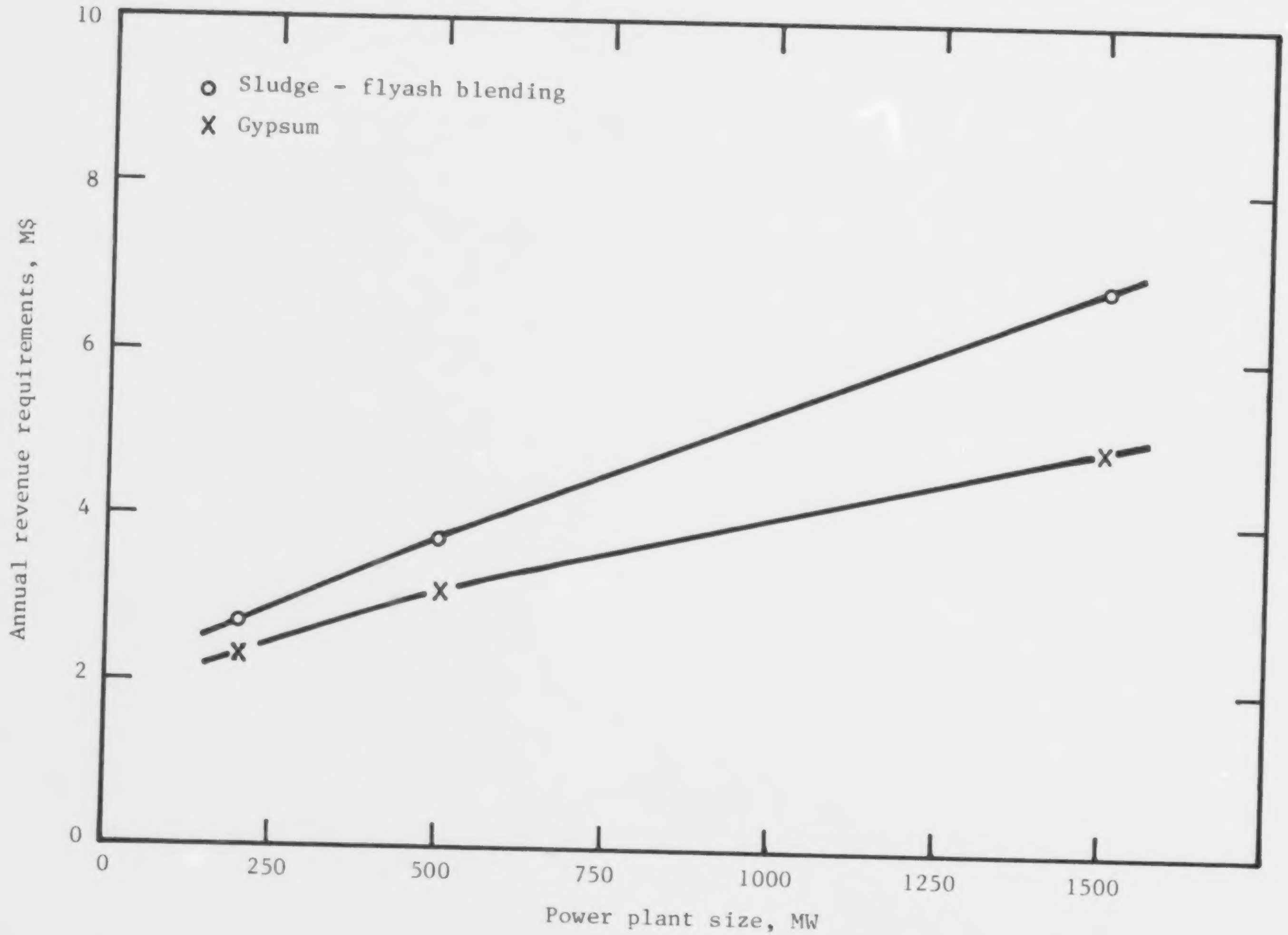


Figure 8. Effect of power plant size on annual revenue requirements. New plant.

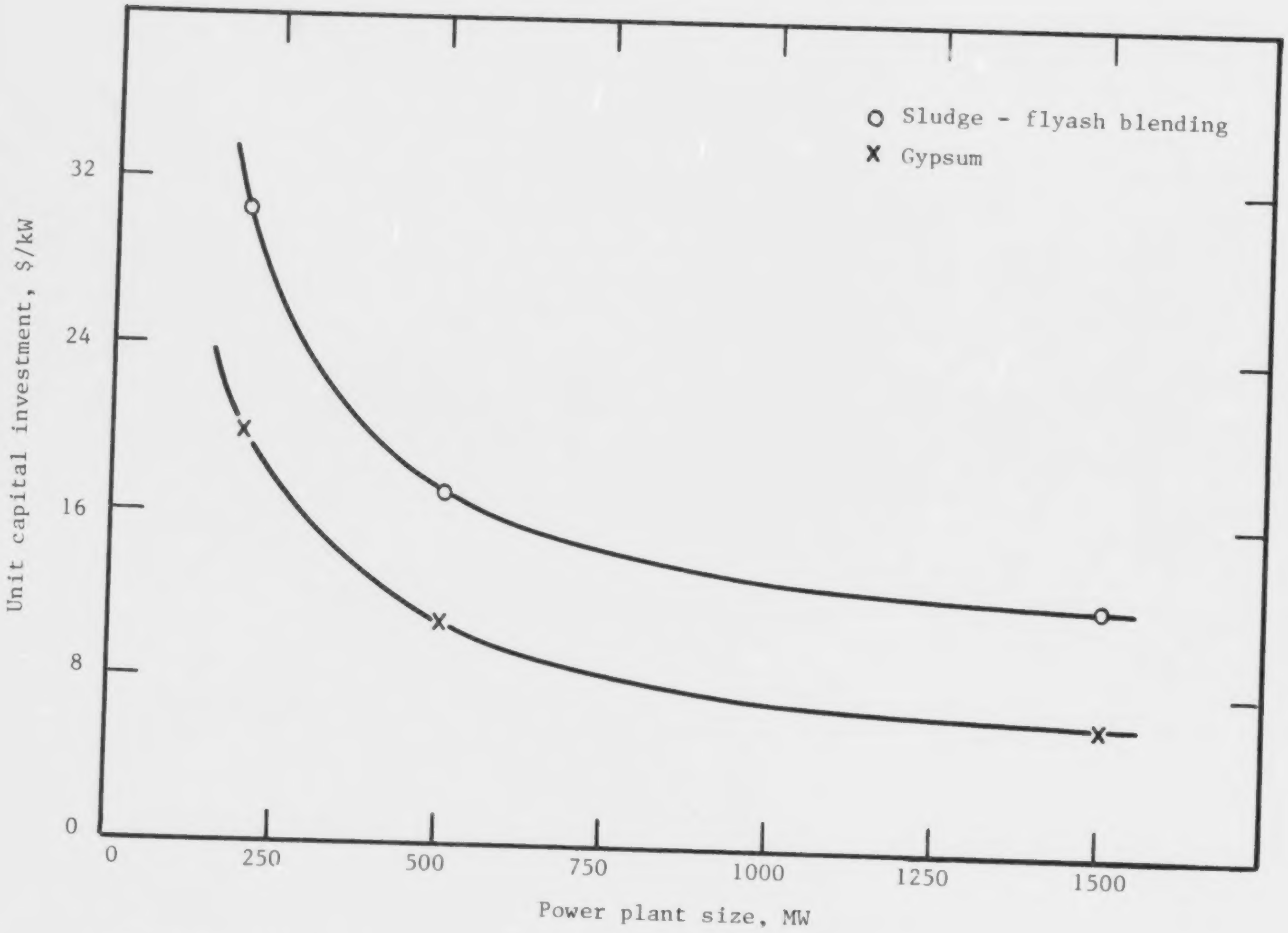


Figure 9. Effect of power plant size on unit capital investment. New plant.

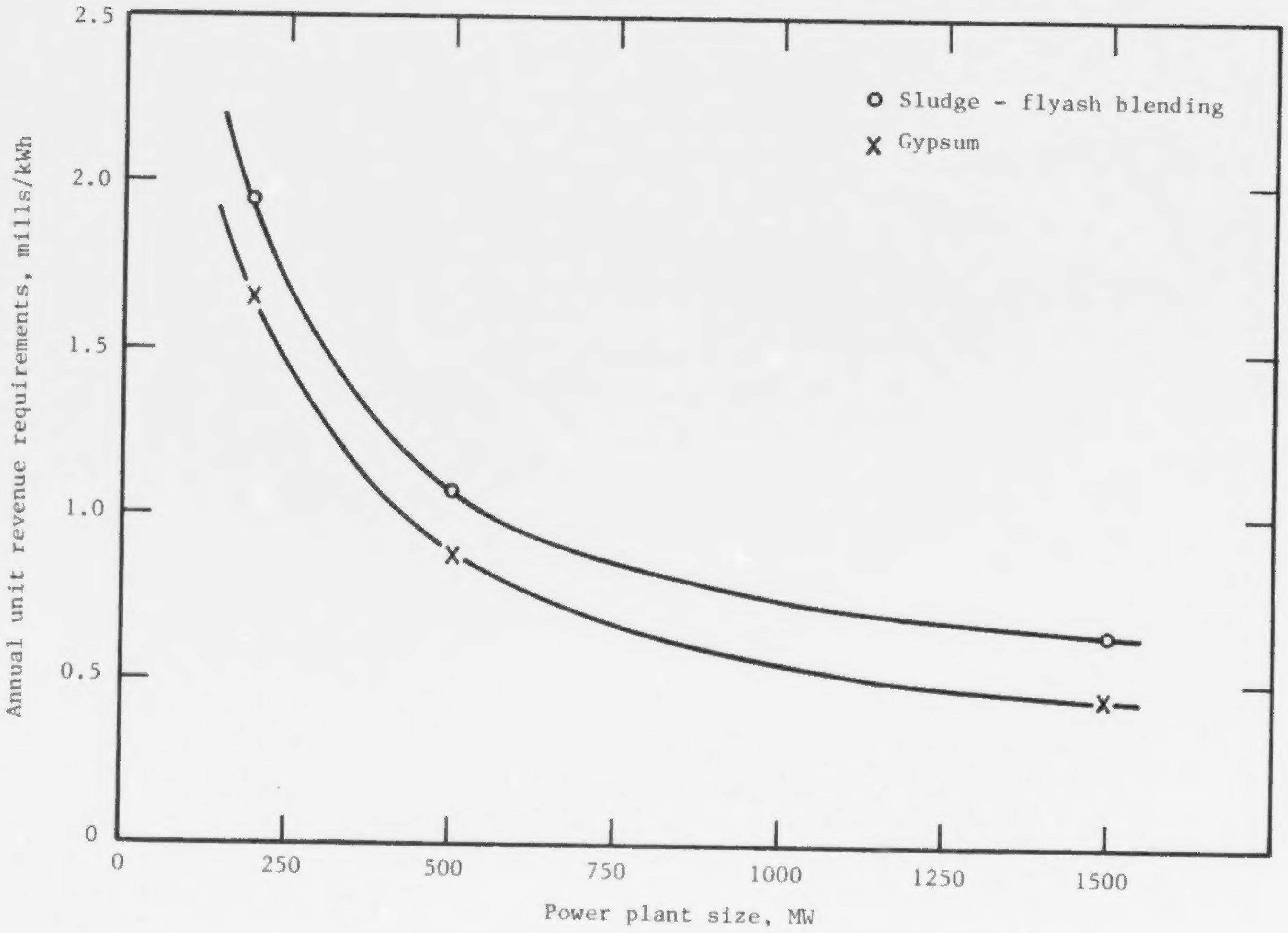


Figure 10. Effect of power plant size on annual unit revenue requirements. New plant.

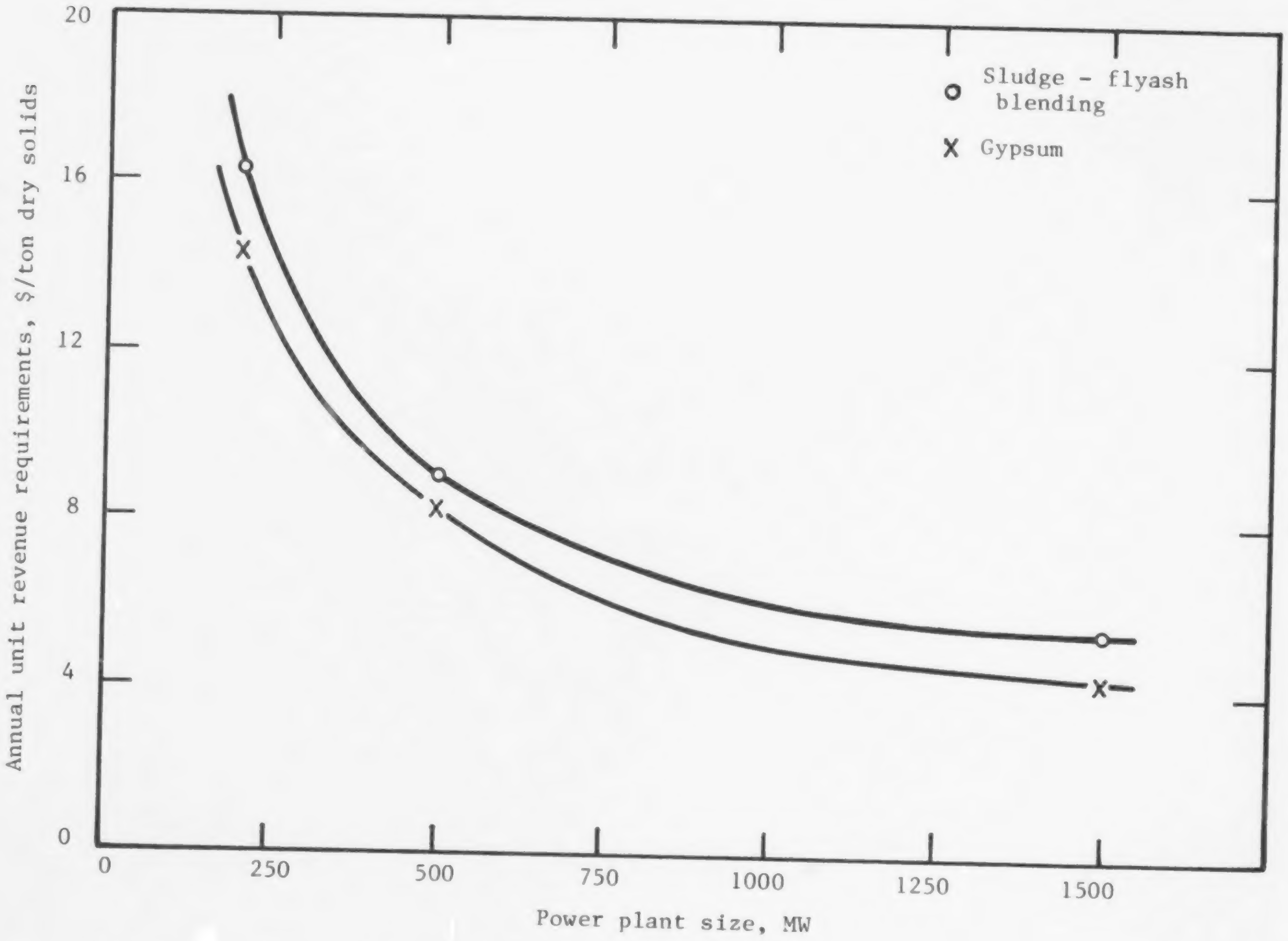


Figure 11. Effect of power plant size on annual unit revenue requirements. New plant.

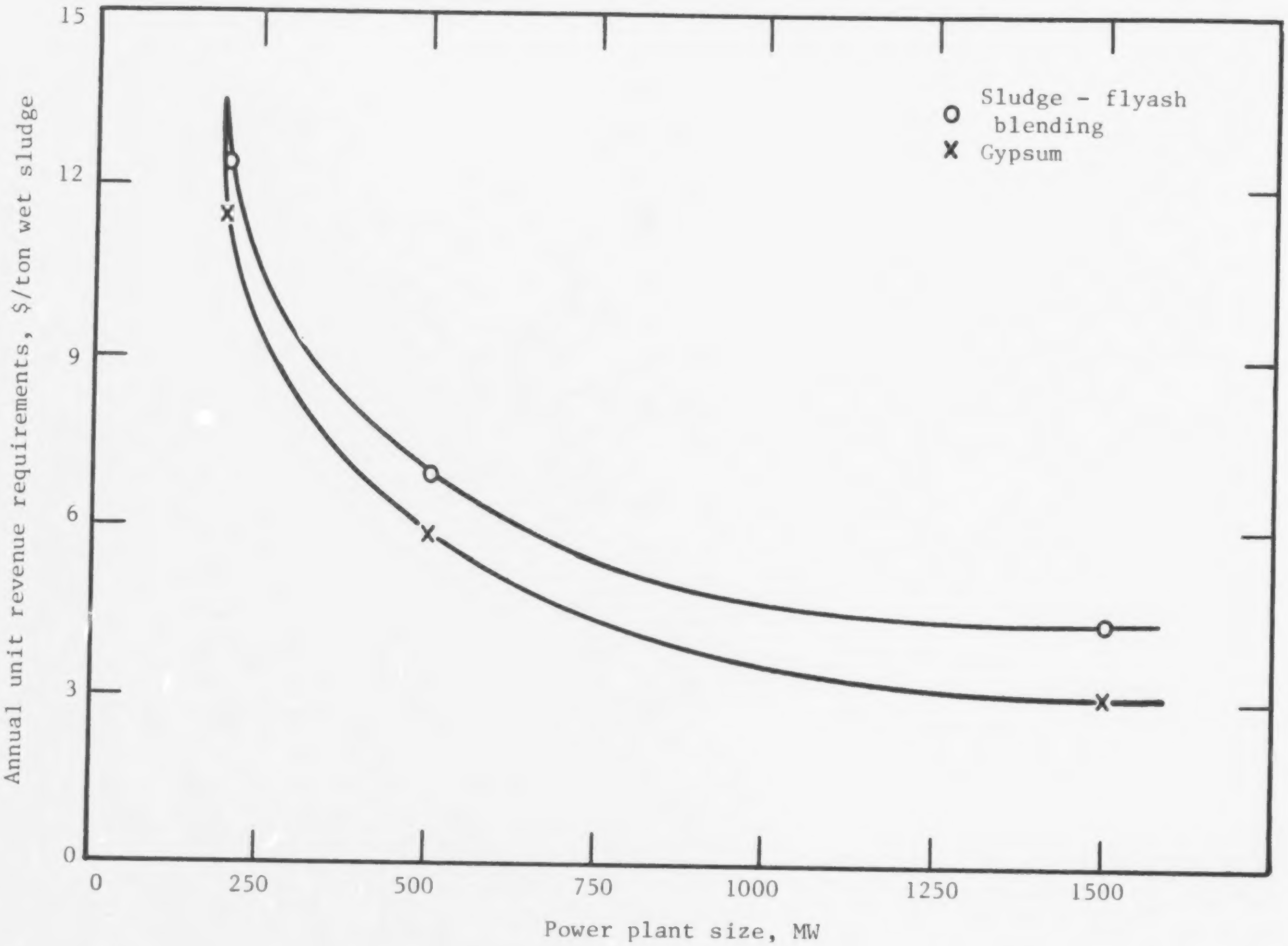


Figure 12. Effect of power plant size on annual unit revenue requirements. New plant.

capital investment. In both cases the increase in costs is slight, as shown in Table 23 and graphically in Figures 13 and 14, as compared to Figures 7 and 8.

TABLE 23. CAPITAL INVESTMENT AND ANNUAL REVENUE REQUIREMENTS FOR DECLINING- AND CONSTANT-LOAD CONDITIONS, k$

Load schedule	200 MW		500 MW		1,500 MW	
	Declining	Constant	Declining	Constant	Declining	Constant
Sludge - flyash blending						
Capital investment	6.126	6,268	8,605	8.955	18,282	19,321
Annual revenue requirements	2,779	2,791	3,773	3,801	6,922	7,012
Gypsum						
Capital investment	3,964	4,093	5.411	5,672	9,826	10,603
Annual revenue requirements	2,327	2,401	3,118	3.146	4,962	5,028

Total Lifetime Revenue Requirements--

In addition to first-year annual revenue requirements, lifetime revenue requirements were calculated for the three power plant sizes for both 30-year declining-load operating schedule and 30-year constant-load operating schedule. The declining-load schedule uses the load schedule described in the premises with a 127,500-hour operating lifetime. The constant-load schedule consists of a 7,000 hr/yr, 210,000-hour operating lifetime.

The yearly and cumulative detailed results of the declining-load schedule are shown in Appendix B and are summarized in Table 24 and Figure 15. The results are given as both actual cost and as costs discounted at 11.6% to the initial year as described in the premises. The same detailed results for the constant-load schedule are shown in Appendix C and are summarized in Table 25 and Figure 16.

Power Plant Remaining Life

Power plants with remaining lives of 25, 20, and 15 years, operating at 7000 hr/yr at the same conditions as the base case, were evaluated. Compared to the base cases, both processes have small decreases in capital investment as shown below and in Figure 17.

Remaining life, years	30 (base case)		25		20		15	
	k$	$/kW	k$	$/kW	k$	$/kW	k$	$/kW
Sludge - flyash blending								
Process equipment	1,985	4.0	2,026	4.1	2,026	4.1	2,026	4.1
Land	536	1.1	389	0.8	242	0.5	137	0.3
Total capital investment	8,605	17.2	8,528	17.1	8,381	16.8	8,276	16.6
Gypsum								
Process equipment	1,179	2.3	1,183	2.4	1,183	2.4	1,183	2.4
Land	403	0.8	154	0.3	95	0.2	56	0.1
Total capital investment	5,411	10.8	5,174	10.3	5,115	10.2	5,076	10.2

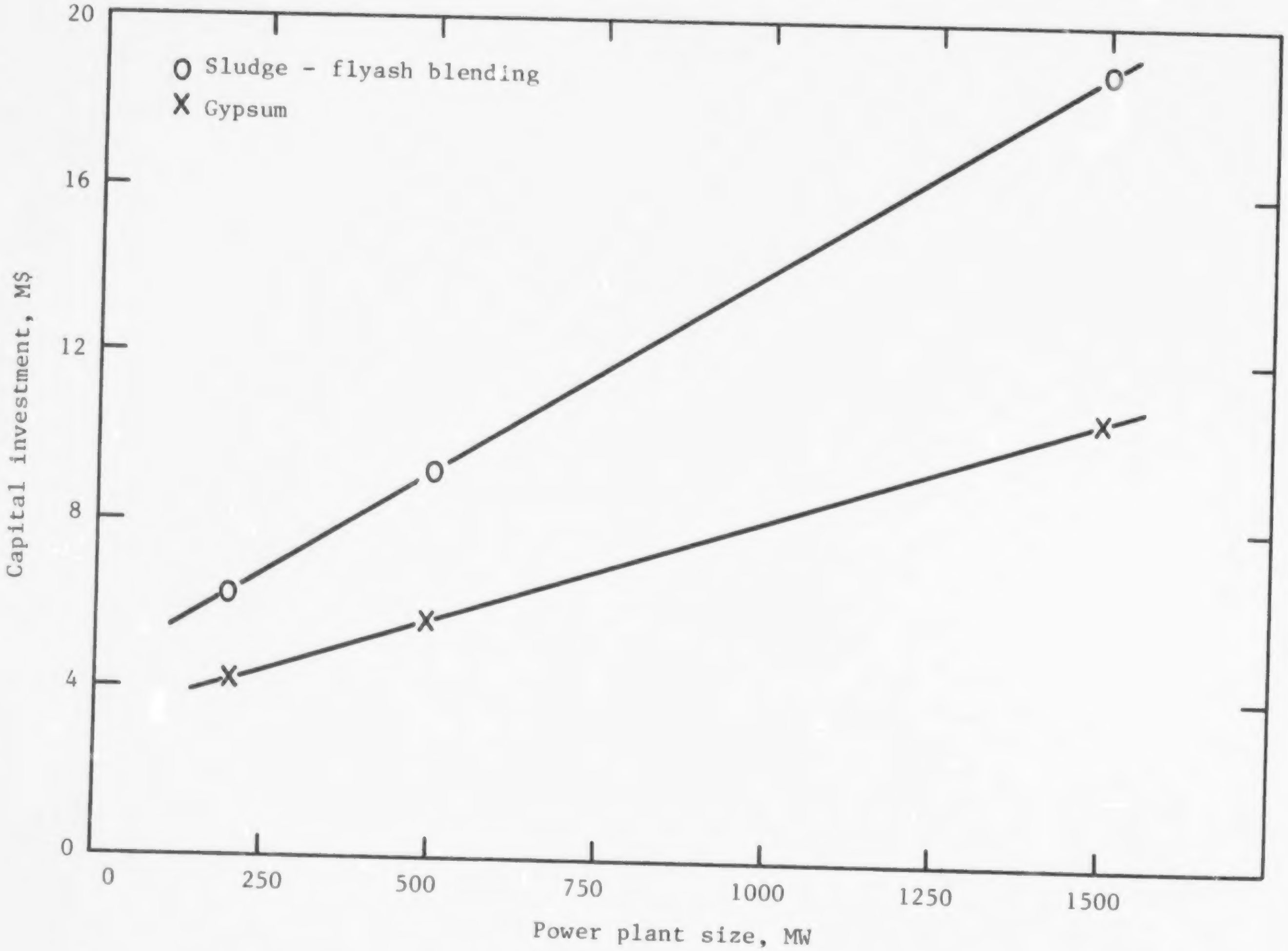


Figure 13. Effect of power plant size on capital investment. New plant operating at constant 7000 hr/yr throughout 30-yr life.

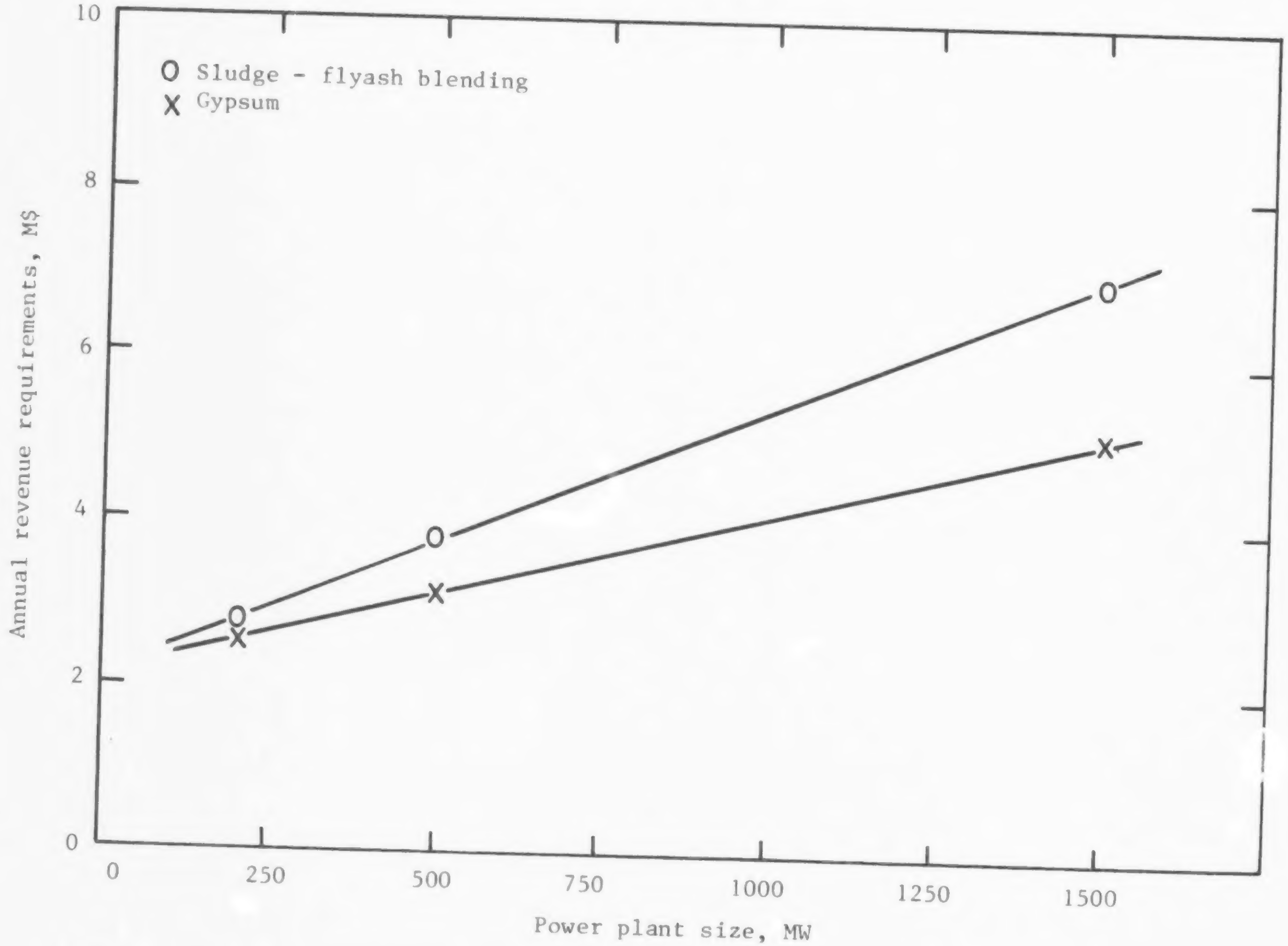


Figure 14. Effect of power plant size on annual revenue requirements. New plant operating at constant 7000 hr/yr throughout 30-yr life.

TABLE 24. SUMMARY OF LIFETIME REVENUE REQUIREMENTS FOR SYSTEMS OPERATING ON A DECLINING-LOAD SCHEDULE OVER THE 30-YEAR LIFE OF THE POWER PLANT[a]

Case[b]	Cumulative actual lifetime revenue requirements, $	Lifetime average unit revenue requirements			Cumulative present worth lifetime revenue requirements, $[c]	Levelized unit revenue requirements[d]		
		Mills/kWh	$/ton dry solids	$/ton wet solids		Mills/kWh	$/ton dry solids	$/ton wet solids
Sludge - flyash blending								
200 MW	70,341,600	2.76	22.95	17.21	23,903,700	2.40	7.80	5.85
500 MW	96,526,800	1.51	12.88	9.66	32,801,900	1.32	4.38	3.28
1500 MW	181,405,400	0.95	8.07	6.05	61,730,100	0.83	2.75	2.06
Gypsum								
200 MW	62,063,000	2.43	21.00	16.80	21,047,100	2.12	7.12	5.70
500 MW	78,072,400	1.22	10.80	8.64	26,513,400	1.07	3.67	2.93
1500 MW	126,375,500	0.66	4.66	5.83	42,998,600	0.56	1.98	1.59

a. Basis: 30-yr life - 7000 hr for 10 yr, 5000 hr for 5 yr, 3500 hr for 5 yr; 1500 hr for 10 yr; Midwest plant location, mid-1980 revenue requirements; constant labor cost assumed over the life of the project.

b. New plants, coal analysis (wt %): 3.5% S (dry), 16% ash, flyash and SO_2 removed to meet NSPS.

c. Discounted at 11.6% to initial year.

d. Equivalent to discounted process cost over life of power plant.

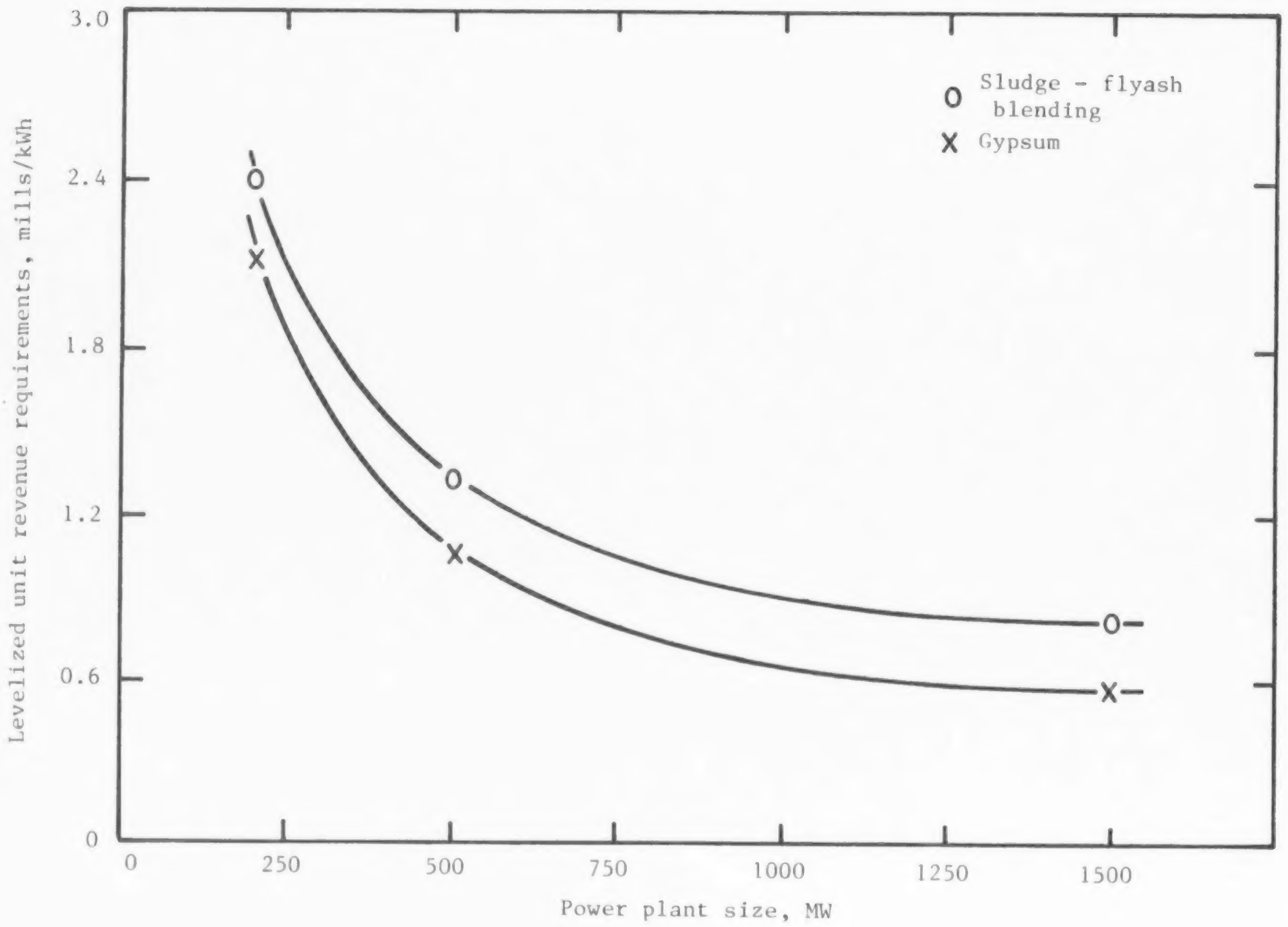


Figure 15. Effect of power plant size on levelized unit revenue requirements. New plant operating with declining annual operating load over 30-yr life.

TABLE 25. SUMMARY OF LIFETIME REVENUE REQUIREMENT FOR SYSTEMS OPERATING AT CONSTANT LOAD OF 7000 HR/YR DURING 30-YEAR LIFE OF THE POWER PLANT[a]

Case[b]	Cumulative actual lifetime revenue requirements, $	Lifetime average unit revenue requirements			Cumulative present worth lifetime revenue requirements, $[c]	Levelized unit revenue requirements[d]		
		Mills/kWh	$/ton dry solids	$/ton wet solids		Mills/kWh	$/ton dry solids	$/ton wet solids
Sludge blending								
200 MW	85,472,400	2.04	17.16	12.70	25,546,100	2.20	5.14	3.80
500 MW	118,395,300	1.13	9.72	7.19	35,351,400	1.22	2.91	2.15
1500 MW	222,596,600	0.71	6.09	4.51	66,989,700	0.77	1.84	1.36
Gypsum								
200 MW	77,691,300	1.85	15.96	12.77	22,691,000	1.95	4.66	3.73
500 MW	98,403,500	0.94	8.26	6.61	28,800,400	0.99	2.43	1.94
1500 MW	161,159,500	0.51	4.51	3.61	47,321,000	0.54	1.33	1.06

a. Basis: Midwest plant location; 1980 revenue requirements; 30-yr life; 7,000 hr/yr operation; 210,000 hr total operating time.
b. New plant; coal analysis (wt %): 3.5% S (dry), 16% ash; flyash and SO_2 removed to meet NSPS.
c. Discounted at 11.6% to initial year.
d. Equivalent to discounted process cost over life of power plant.

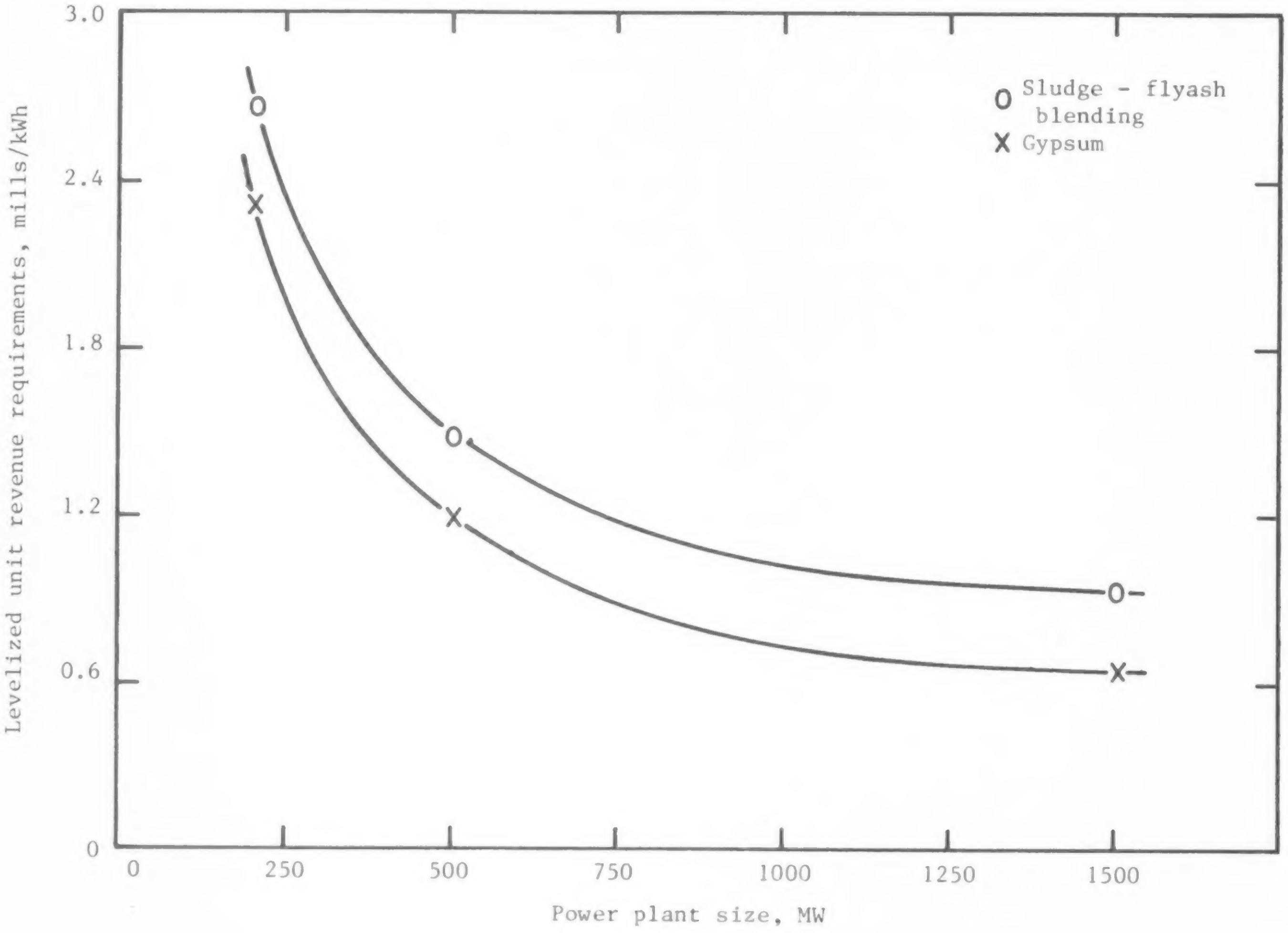


Figure 16. Effect of power plant size on levelized unit revenue requirements. New plant operating at constant 7000 hr/yr throughout 30-yr life.

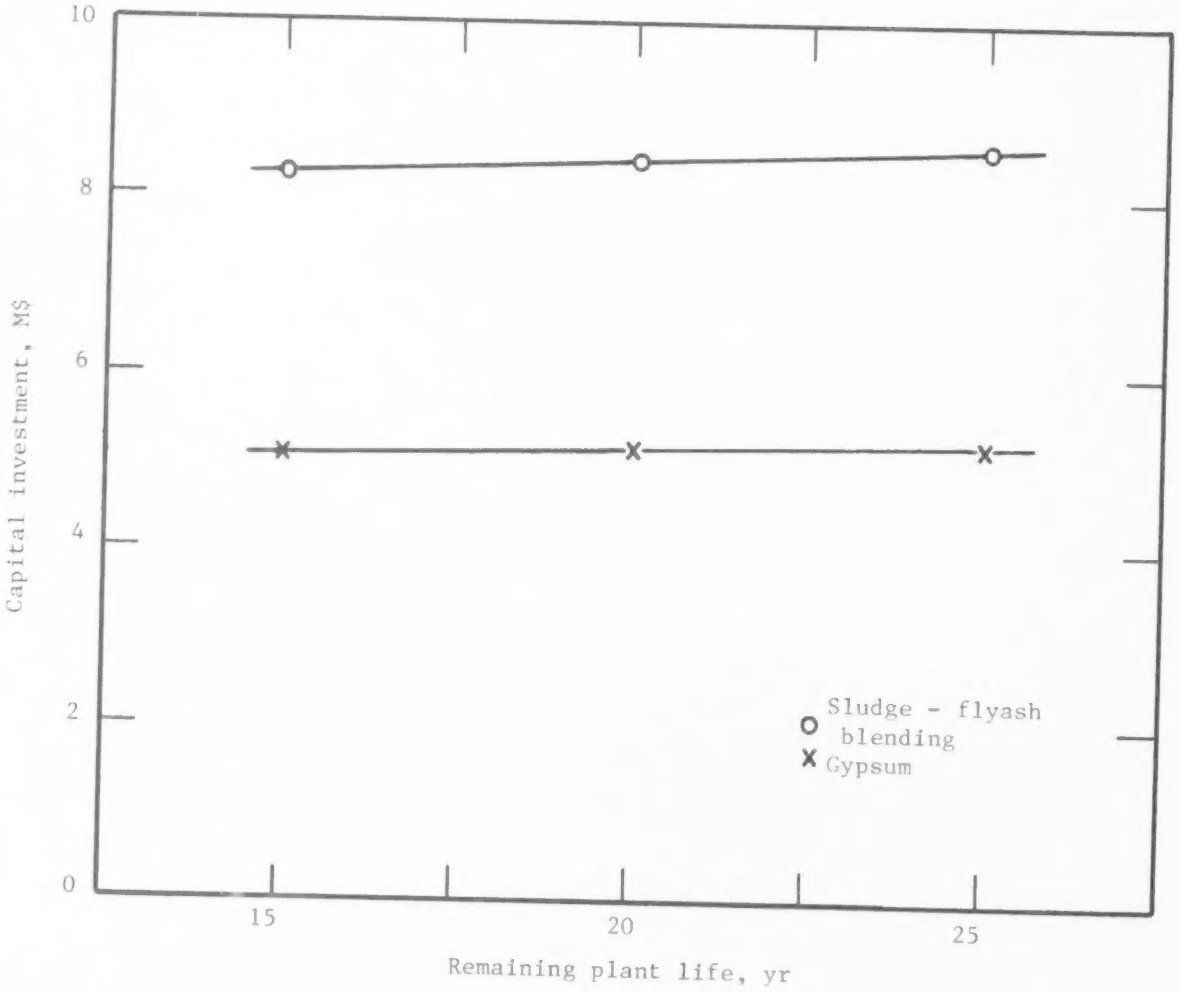


Figure 17. Effect of remaining plant life on capital investment. 500-MW plant.

Process equipment and land costs produce the differences in capital investment shown. The difference in process equipment costs is a result of using a 9000 Btu/kWh heat rate for new plants and 9200 Btu/kWh for existing plants. Land costs are based on the area needed to dispose ot the waste produced during the remaining life of the plant.

Annual revenue requirements, shown below and in Figure 18, increase primarily as a result of increased capital charges. The increase in capital charges is due to accelerated depreciation charges, partially offset by a lower interim replacement allowance, as discussed in the premises.

Remaining life, years	30 (base case)		25		20		15	
	k$	Mills/kWh	k$	Mills/kWh	k$	Mills/kWh	k$	Mills/kWh
Sludge - flyash blending	3,773	1.08	3,852	1.10	3,876	1.10	3,982	1.14
Gypsum	3,116	0.89	3,143	0.89	3,160	0.90	3,227	0.92

Sulfur in Coal

The sulfur content of coal was evaluated at 2% and 5% in addition to the base case 3.5%. The primary effects on capital investment are on process equipment size, mobile equipment required, and land requirements as shown below and in Figure 19.

Sulfur in coal, wt % dry	2.0		3.5 (base case)		5.0	
	k$	$/kW	k$	$/kW	k$	$/kW
Sludge - flyash blending						
Process equipment	1,532	3.1	1,985	4.0	2,465	4.9
Mobile equipment	517	1.0	581	1.2	698	1.4
Land	340	0.7	536	1.1	735	1.5
Total capital investment	7,356	14.7	8,605	17.2	10,073	20.1
Gypsum						
Process equipment	1,031	2.1	1,179	2.3	1,290	2.6
Mobile equipment	435	0.9	498	1.0	575	1.2
Land	284	0.6	403	0.8	511	1.0
Total capital investment	4,782	9.6	5,411	10.8	5,884	11.8

Annual revenue requirements are shown below and in Figure 20. The differences are largely a result of differences in conversion costs, particularly those related to transportation and landfill operations, resulting from the different quantities of waste handled.

Sulfur in coal, wt % dry	2.0		3.5 (base case)		5.0	
	k$	Mills/kWh	k$	Mills/kWh	k$	Mills/kWh
Sludge - flyash blending	3,224	0.92	3,773	1.08	4,282	1.22
Gypsum	2,707	0.77	3,118	0.89	3,252	0.95

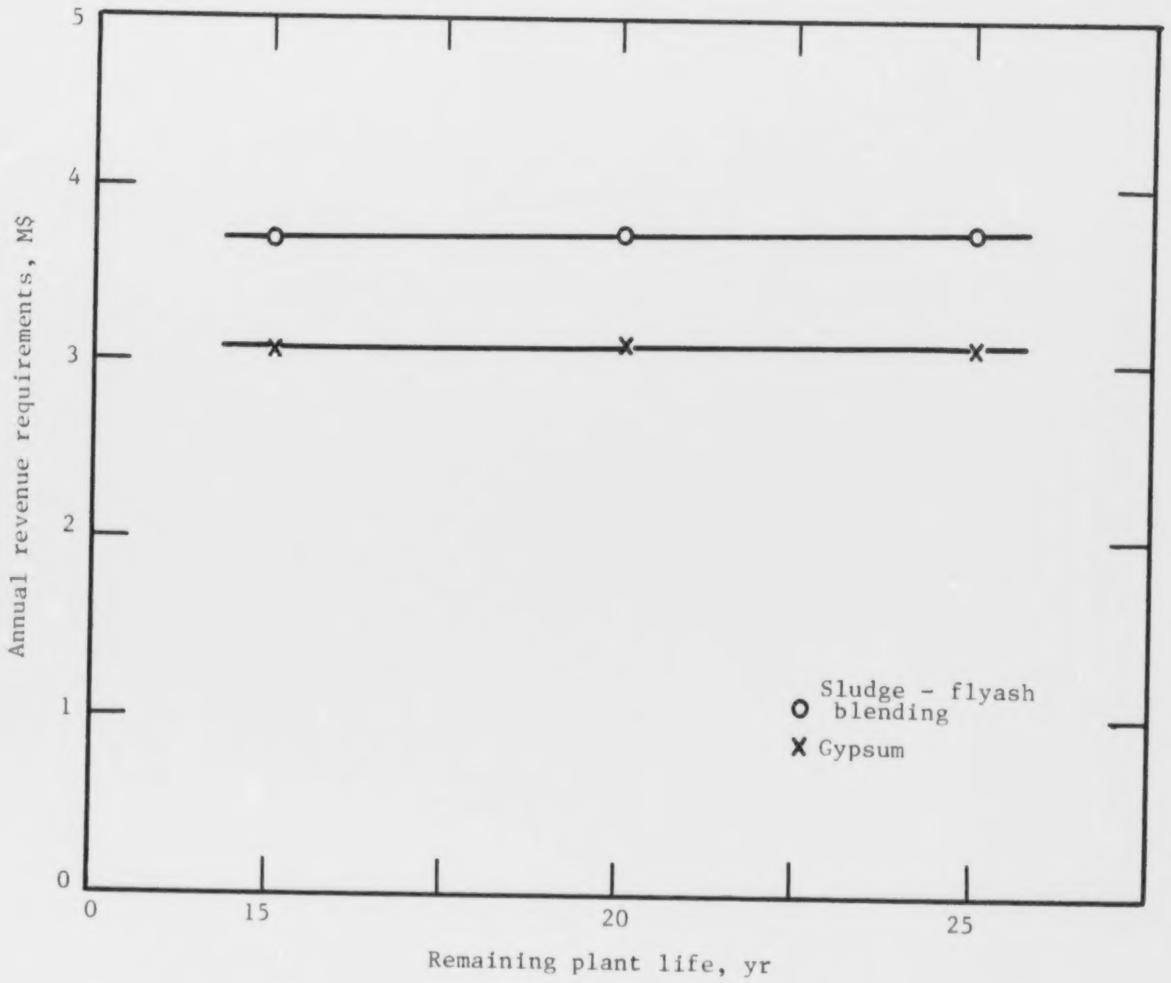


Figure 18. Effect of remaining plant life on annual revenue requirements. 500-MW plant.

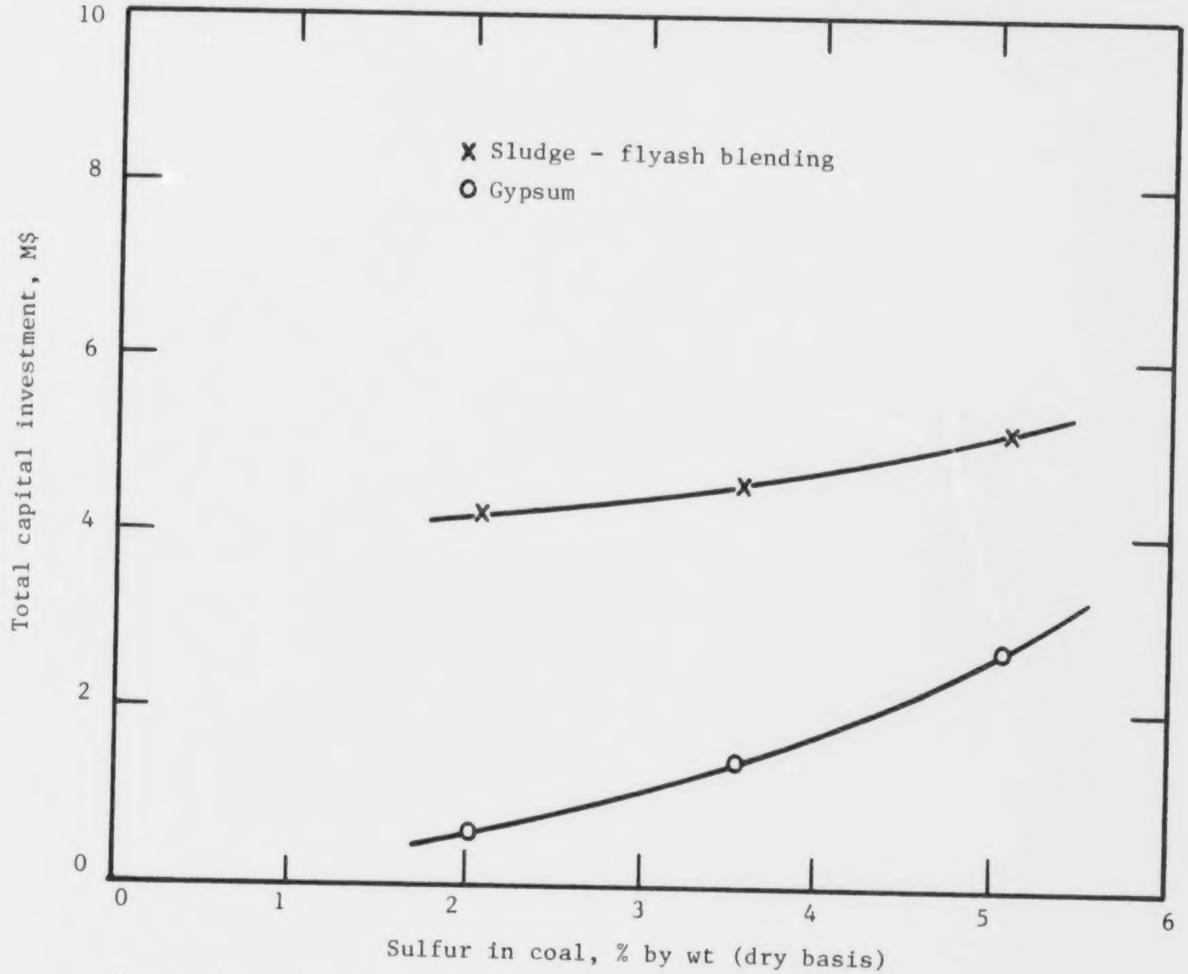


Figure 19. Effect of sulfur content of coal on capital investment. New 500-MW plant.

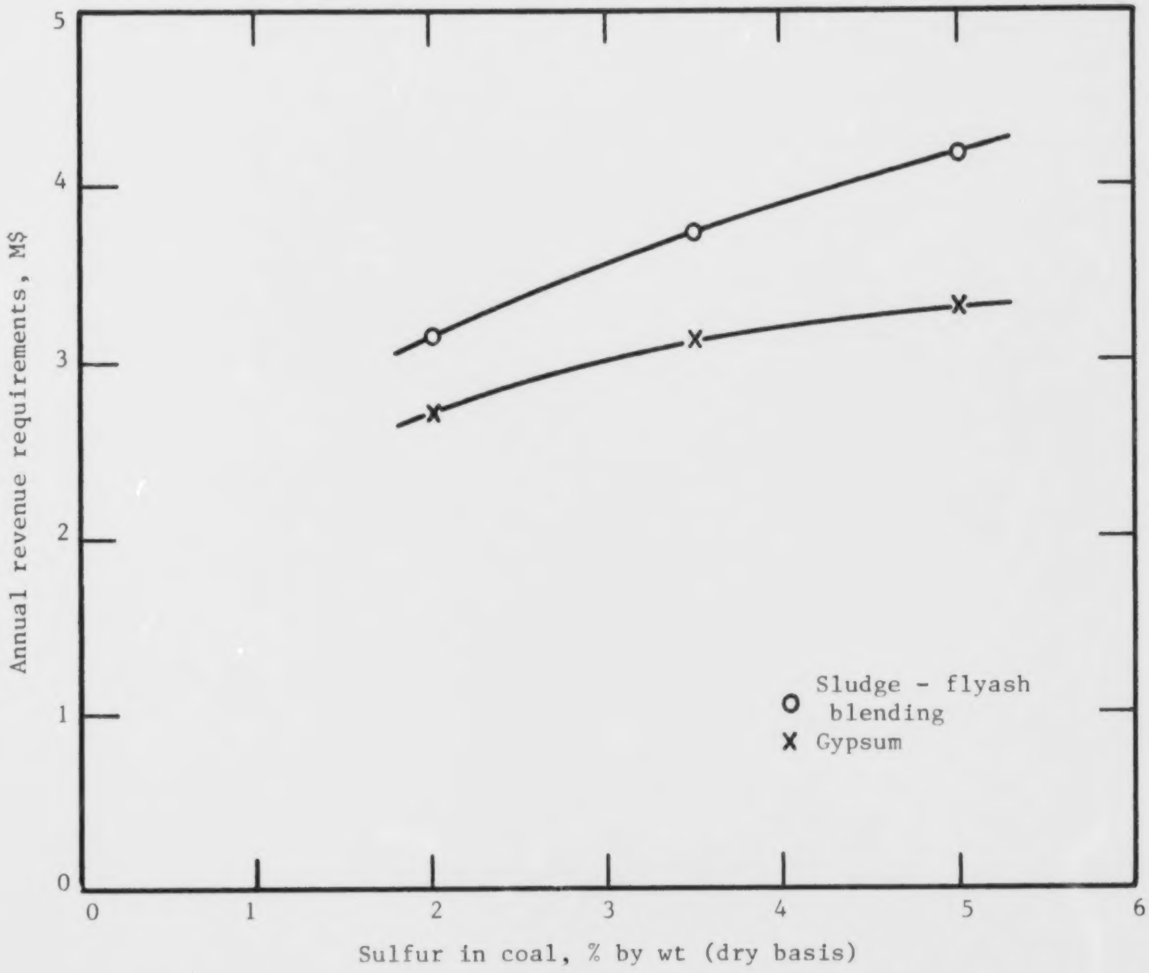


Figure 20. Effect of sulfur content of coal on annual revenue requirements. New 500-MW plant.

Ash in Coal

The ash content of the coal was evaluated at 12% and 20% in addition to the base case 16%. As in the case of sulfur in coal, ash content affects capital investment primarily in the size of process equipment, mobile equipment, and land requirements, as shown below and in Figure 21.

Ash in coal, wt %	12		16 (base case)		20	
	k$	$/kW	k$	$/kW	k$	$/kW
Sludge - flyash blending						
Process equipment	1,788	3.6	1,985	4.0	2,173	4.3
Mobile equipment	581	1.2	581	1.2	665	1.3
Land	459	0.9	536	1.1	627	1.3
Total capital investment	7,917	15.8	8,605	17.2	9,309	18.6
Gypsum						
Process equipment	1,109	2.2	1,179	2.4	1,271	2.5
Mobile equipment	435	0.9	498	1.0	498	1.0
Land	329	0.7	403	0.8	480	1.0
Total capital investment	5,042	10.1	5,411	10.8	5,707	11.4

Annual revenue requirements, as shown below and in Figure 22, were affected by conversion costs, particularly transportation and landfill operations.

Ash in coal, wt %	12		16 (base case)		20	
	k$	Mills/kWh	k$	Mills/kWh	k$	Mills/kWh
Sludge - flyash blending	3,617	1.03	3,773	1.08	3,965	1.13
Gypsum	3,018	0.86	3,118	0.89	3,206	0.92

Lime Versus Limestone

The use of lime instead of limestone as the scrubber absorbent was evaluated for both the sludge - flyash blending process and the gypsum process. From a disposal standpoint the main process differences were a 10% solids slurry from the scrubbers instead of 15% and a 1.0:1.0 absorbent to sulfur-removed stoichiometry for both cases instead of 1.5:1.0 for the sludge - flyash blending process and 1.1:1.0 for the gypsum process when using limestone.

The main effects on capital investment are a reduction in process equipment costs and land requirements because of the absence of unreacted absorbent in the waste slurry. For the gypsum process the differences are small because of the small differences in stoichiometry between the lime and limestone processes.

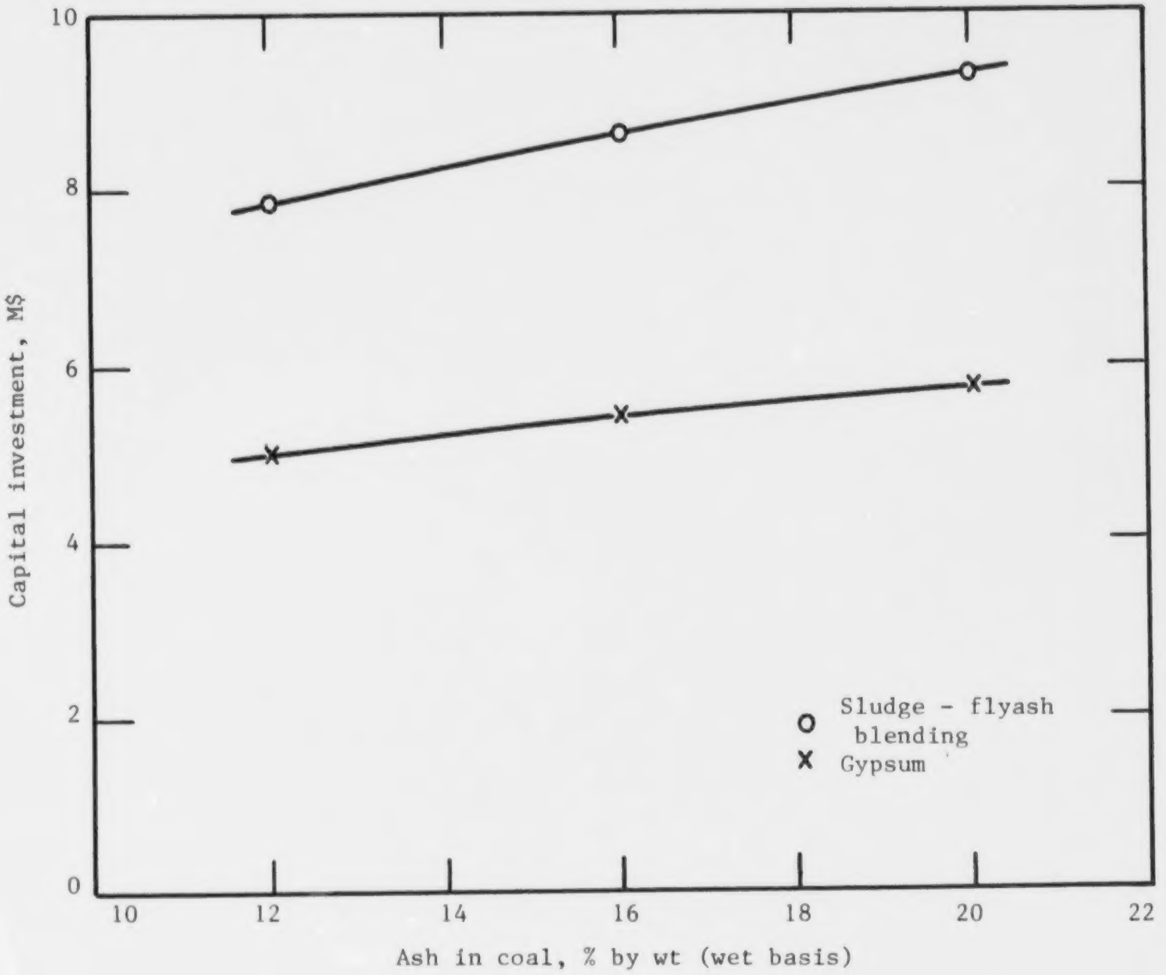


Figure 21. Effect of ash in coal on capital investment. New 500-MW plant.

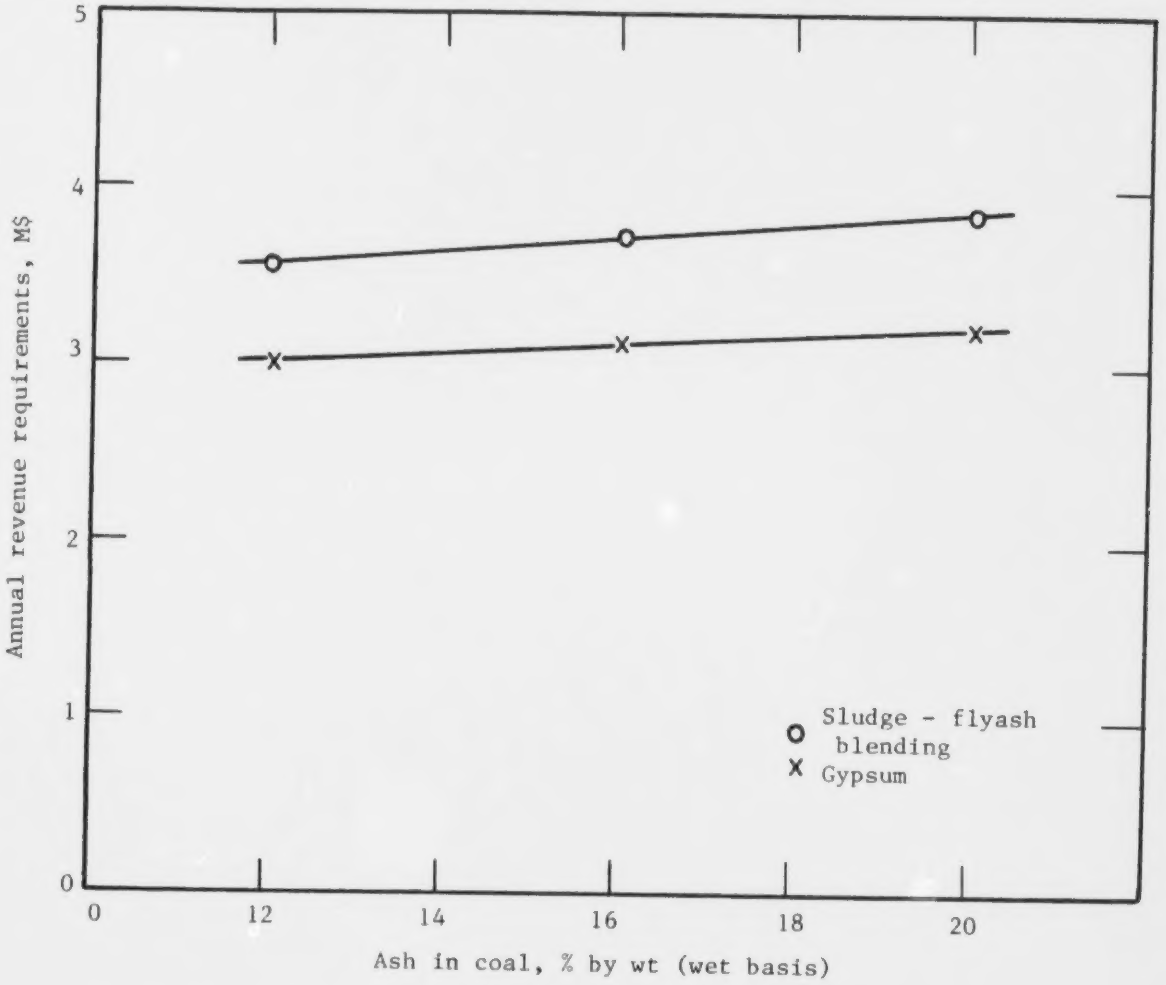


Figure 22. Effect of ash in coal on annual revenue requirements. New 500-MW plant.

	Sludge - flyash blending				Gypsum			
	Base case		Lime		Base case		Lime	
	k$	$/kW	k$	$/kW	k$	$/kW	k$	$/kW
Process equipment	1,985	4.0	1,838	3.7	1,179	2.4	1,167	2.3
Mobile equipment	581	1.2	581	1.2	498	1.0	455	0.9
Land	536	1.1	452	0.9	403	0.8	389	0.8
Total capital investment	8,605	17.2	8,178	16.4	5,411	10.8	5,315	10.6

Annual revenue requirements, as shown below, are affected by lower transportaion and landfill operation costs. The effects are slight in the gypsum process because of the small stoichiometry differences.

Sludge - flyash blending				Gypsum			
Base case		Lime		Base case		Lime	
k$	Mills/kWh	k$	Mills/kWh	k$	Mills/kWh	k$	Mills/kWh
3,773	1.08	3,650	1.04	3,118	0.89	3,104	0.89

Distance to Disposal Site

Distances of 5 and 10 miles to the disposal site were compared to the base-case distance of 1 mile for both processes. In these case variations the only capital-investment direct cost significantly affected is mobile equipment as shown below and in Figure 23.

Distance to disposal site	1 mile (base case)		5 miles		10 miles	
	k$	$/kW	k$	$/kW	k$	$/kW
Sludge - flyash blending						
Mobile equipment	581	1.2	777	1.6	992	2.0
Total capital investment	8,605	17.2	8,969	17.9	9,334	18.7
Gypsum						
Mobile equipment	498	1.0	712	1.4	849	1.7
Total capital investment	5,411	10.8	5,750	11.5	6,005	12.0

Annual revenue requirements were increased by costs related to transportation--particularly disposal labor and supervision and truck fuel and maintenance--as shown below and in Figure 24.

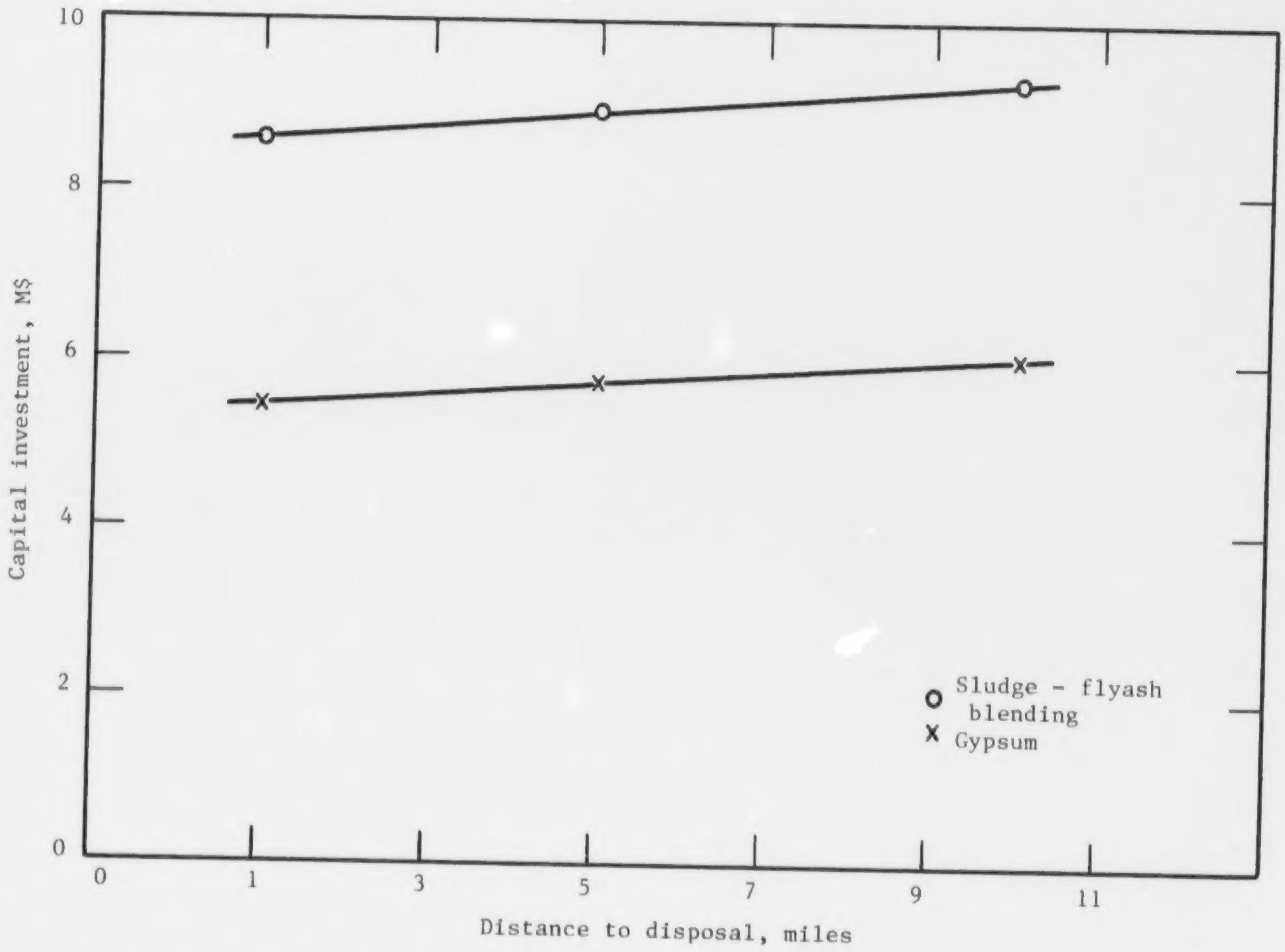


Figure 23. Effect of distance to disposal site on capital investment. New 500-MW plant.

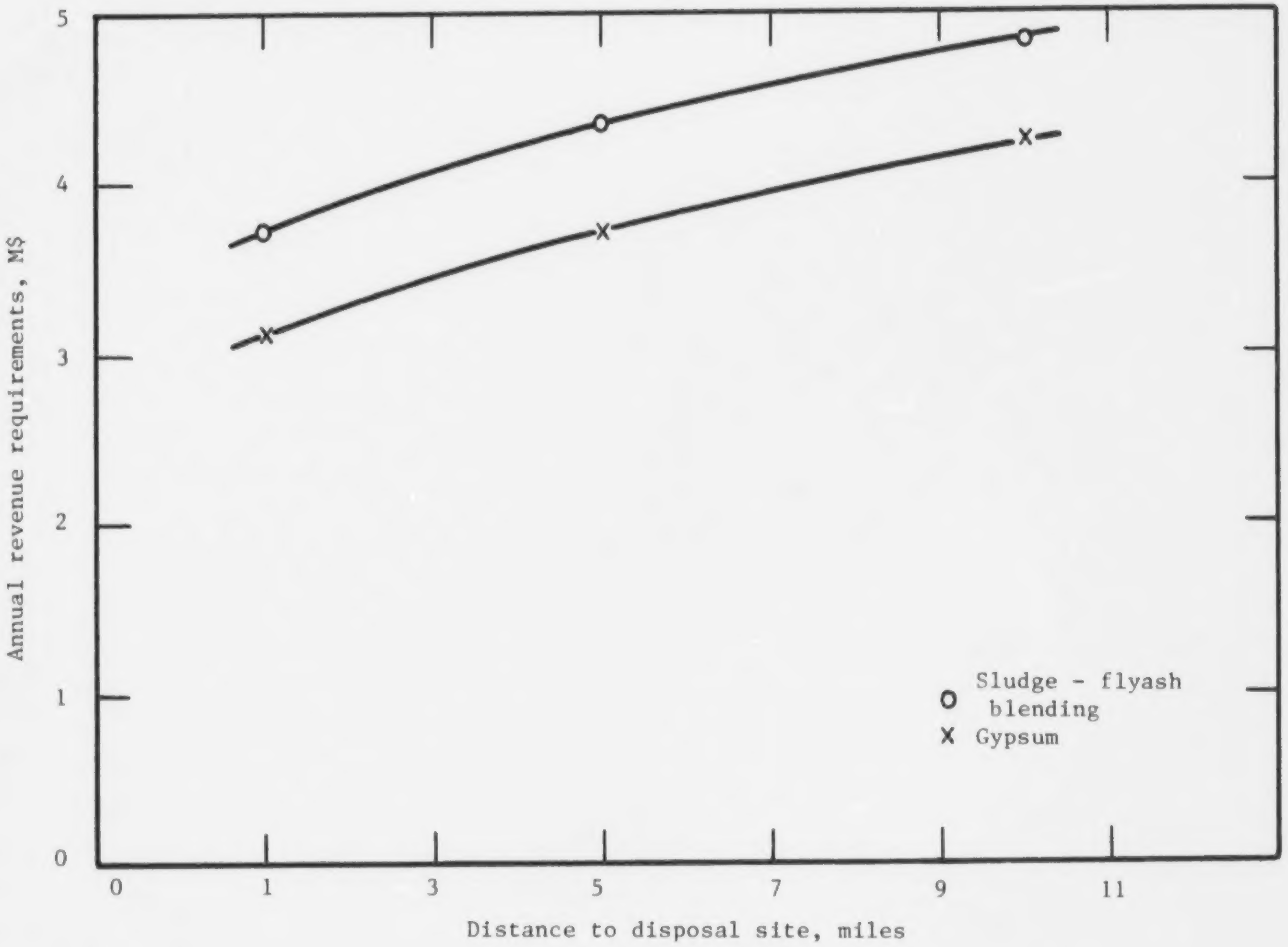


Figure 24. Effect of distance to disposal site on annual revenue requirements. New 500-MW plant.

Distance to disposal site	1 mile (base case)		5 miles		10 miles	
	k$	Mills/kWh	k$	Mills/kWh	k$	Mills/kWh
Sludge - flyash blending						
Disposal labor	745	0.21	1,042	0.30	1,191	0.34
Trucks	33	0.01	110	0.03	214	0.06
Total annual revenue requirements	3,773	1.08	4,425	1.26	4,891	1.40
Gypsum						
Disposal labor	745	0.21	1,042	0.30	1,192	0.34
Trucks	30	0.01	99	0.03	194	0.06
Total annual revenue requirements	3,118	0.89	3,694	1.05	4,286	1.22

Sludge - Flyash Blending Stoichiometry

A case variation for the sludge - flyash blending process was made using a 1.3:1.0 calcium carbonate to sulfur-removed stoichiometry instead of the base-case 1.5:1.0 stoichiometry. The main effects are a reduction in process equipment costs and land requirements. Process equipment cost is 1,771 k$, or 3.5 $/kW, and land cost is 497 k$, or 1.0 $/kW, compared to the base-case process equipment cost of 1,985 k$, or 4.0 $/kW, and land cost of 536 k$, or 1.1 $/kW. Total capital investment is 8,160 k$, or 16.3 $/kW, for the 1.3:1.0 stoichiometry process as compared to 8,605 k$, or 17.2 $/kW, for the base case.

Annual revenue requirements are affected by slight reductions in land preparation and transportation costs, and by costs related to capital investment. Annual revenue requirements for the 1.3:1.0 stoichiometry process are 3,673 k$, or 1.04 mills/kWh, as compared to 3,773 k$, or 1.08 mills/kWh, for the base case.

Sludge - Flyash Layering

For the sludge - flyash blending process a case variation was determined for separate transportation of dewatered sludge and flyash to the disposal site where they were dumped in alternate layers. The major differences between the layering disposal method and the base case are mobile equipment costs resulting from the more complex landfill operations in which two materials are deposited simultaneously. Mobile equipment cost is 751 k$, or 1.5 $/kW, for the layering method, compared to 581 k$, or 1.2 $/kW, for the base case. Total capital investment for the layering method is 8,743 k$, or 17.5 $/kW, compared to 8,605 k$, or 17.2 $/kW, for the base case.

Annual revenue requirements increase slightly in the layering case by additional equipment operating and maintenance costs, offset by slightly lower electrical costs. Annual revenue requirements for the layering case are 3,866 k$, or 1.10 mills/kWh, compared to 3,773 k$, or 1.08 mills/kWh, for the base case.

Waste Production Rate

The rate of waste production differs for most cases. In several cases the waste rate is the most significant variable for the case. The annual revenue requirements were calculated as unit revenue requirements based on dollars per ton on the basis of wet waste and of dry solids produced. These unit revenue requirements for a range of waste production rates are shown in Figures 25 and 26.

Land Requirements

Land requirements are almost completely a function of disposal requirements, based on the premise conditions for percent solids, bulk density, and landfill depth. The land requirements in acres and as a percentage of total capital investment are shown in Table 26. The land requirements range from 756 acres for the 1500-MW plant, sludge - flyash blending process with a constant 7000 hr/yr operating schedule to 16 acres in the 15-year-old 500-MW plant with the gypsum process. For the base cases, the sludge - flyash blending process requires 153 acres and the gypsum process requires 115 acres. In contrast to the large acreage requirements, land costs range from 1% to 20% of the total capital investment and for most cases are less than 10%.

Comparison with Other Waste Disposal Processes

The sludge - flyash blending process and the gypsum process can also be compared with untreated-sludge ponding and the chemical-treatment processes previously evaluated (3). Table 27 shows summarized capital investments and annual revenue requirements for untreated ponding, the three chemical-treatment processes previously evaluated, and the sludge - flyash blending and gypsum processes. Areas in which the major cost differences occur are shown separately. In the untreated-sludge ponding process the 15% solids sludge is pumped directly to an earthen-diked pond. In the Dravo ponding process it is dewatered to 35% solids, treated with additives, and pumped to a pond where it settles and hardens. The similar Dravo landfill process uses the same process but the hardened waste is removed and discarded as landfill, thus reducing land requirements. Both the IUCS and Chemfix processes treat 60% solids dewatered sludge with chemical additives and discard it as landfill.

The capital investments of the seven processes are ranked below.

	Disposal only		Scrubbers + disposal	
	k$	$/kW	k$	$/kW
Gypsum + air oxidation	7,714	15.4	44,082	88.2
IUCS	10,717	21.4	47,085	94.2
Dravo landfill	12,670	25.3	49,038	98.1
Chemfix	13,531	27.1	49,849	99.7
Untreated ponding	17,211	34.4	53,579	107.2
Sludge - flyash blending + ESP units	18,219	36.4	54,587	109.2
Dravo ponding	24,114	48.2	60,482	121.0

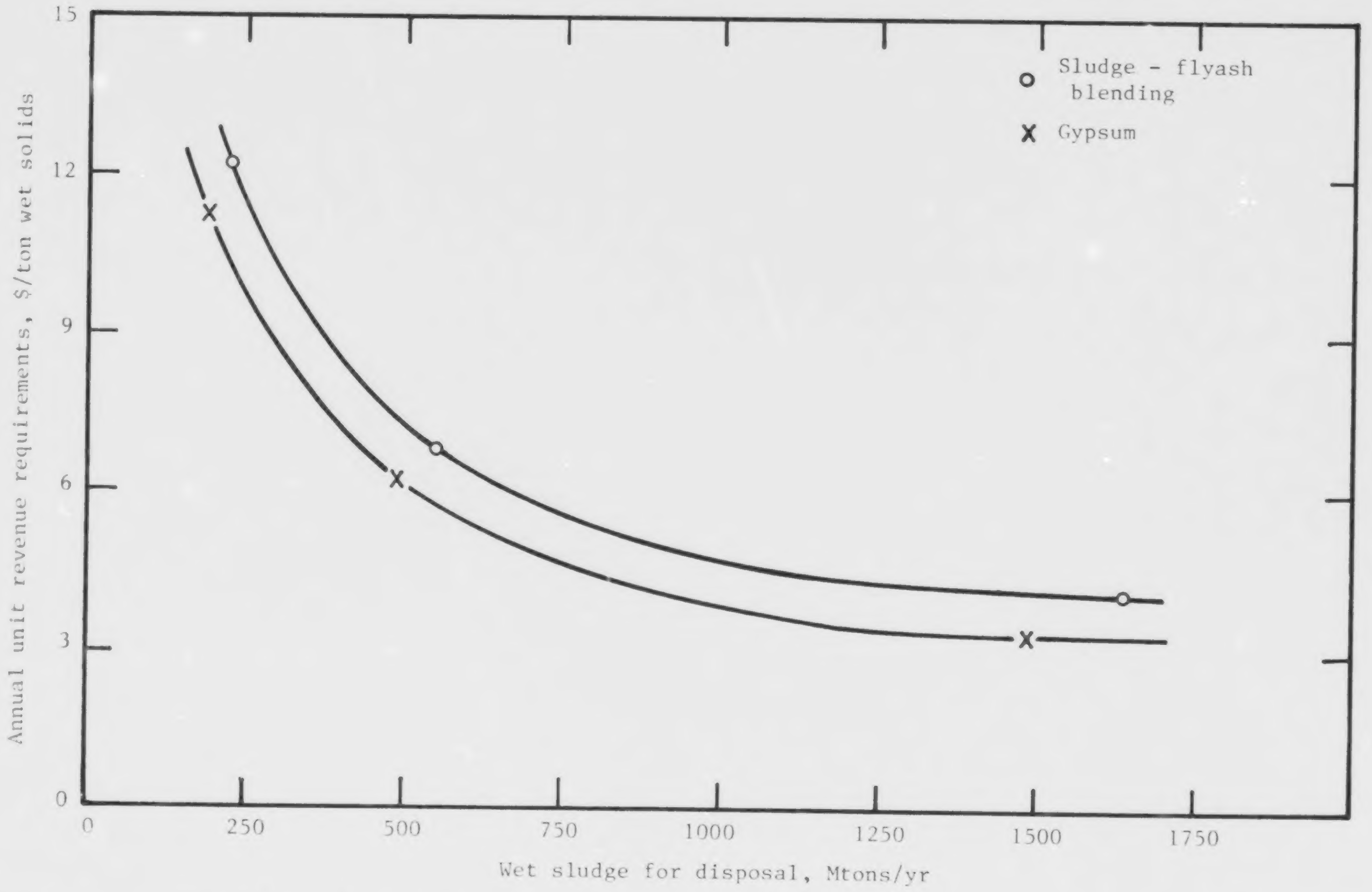


Figure 25. Effect of sludge rate on annual unit revenue requirements, wet basis.

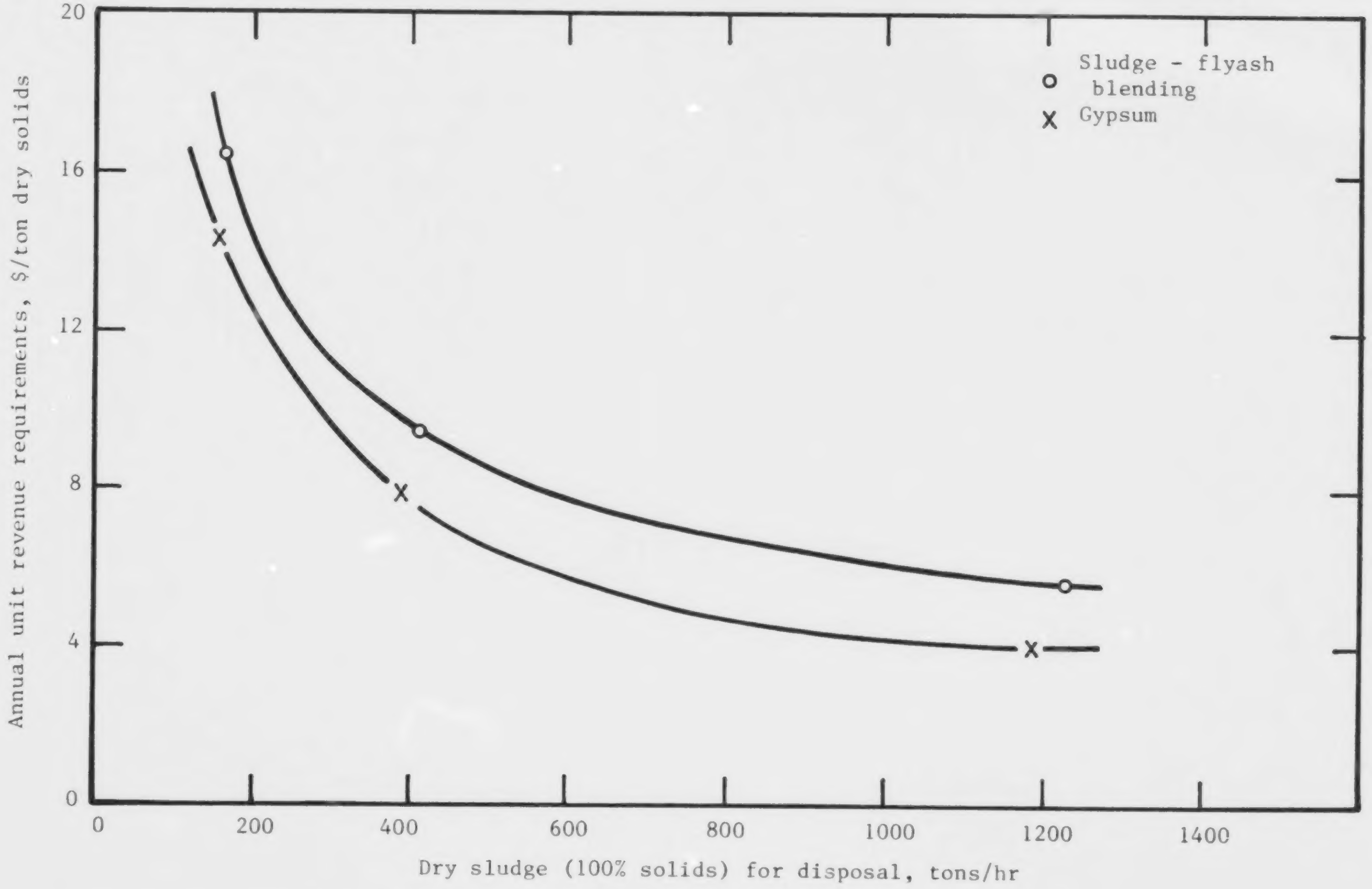


Figure 26. Effect of sludge rate on annual unit revenue requirements, dry basis.

TABLE 26. LAND REQUIREMENTS AND COSTS

Case[a]	Sludge - flyash blending Acres	Sludge - flyash blending % capital investment	Gypsum Acres	Gypsum % capital investment
Base case	153	6	115	8
Variation from base case				
200 MW	63	4	47	4
1500 MW	459	9	343	12
Existing, 25-year remaining life	111	5	44	3
Existing, 20-year remaining life	69	3	27	2
Existing, 15-year remaining life	39	2	16	1
2% sulfur in coal	97	5	81	6
5% sulfur in coal	210	7	146	9
12% ash in coal	131	6	94	7
20% ash in coal	179	7	137	8
Lime scrubbing process	129	6	111	7
5 miles to disposal	153	6	115	7
10 miles to disposal	153	6	115	7
7000 hr/yr operating profile	252	10	188	12
200 MW, 7000 hr/yr operating profile	104	6	77	7
1500 MW, 7000 hr/yr operating profile	756	14	565	19
Sludge - flyash layering	153	6	-	-
1.3 stoichiometry	142	6	-	-

[a] The unit cost of land for all cases is $3500/acre.

TABLE 27. BASE-CASE COST COMPARISON OF SEVEN DISPOSAL ALTERNATIVES

	Untreated sludge ponding		Sludge-fly ash blending		Gypsum		Dravo ponding		Dravo landfill		IUCS		Chemfix	
	k$	%	k$	%	k$	%	k$	%	k$	%	k$	%	k$	%
Capital investment														
Pond construction	7,251	42					7,410	31						
Mobile equipment			581	7	498	9			739	6	581	6	442	3
Other direct investment	1,914	11	3,374	39	1,893	35	4,943	20	4,834	38	4,301	40	5,775	43
Total direct investment	9,165	53	3,955	46	2,391	44	12,353	51	5,573	44	4,882	46	6,217	46
Land	1,423	8	536	6	403	8	1,450	6	1,007	8	676	6	693	5
Other capital investment	6,623	39	4,114	48	2,617	48	10,311	43	6,090	48	5,159	48	6,621	49
Total	17,211	100	8,605	100	5,411	100	24,114	100	12,670	100	10,717	100	13,531	100
Total with ESP or oxidation			18,219[b]		7,714[c]									
Total with scrubbers[a]	53,579		54,587[b]		44,082[c]		60,482		49,038		47,085		49,849	
Annual revenue requirements														
Raw materials							1,840	27	1,840	28	859	16	2,177	31
Conversion	577	18	1,564	41	1,460	47	979	15	1,835	28	1,791	34	1,758	25
Total direct costs	577	18	1,564	41	1,460	47	2,819	42	3,676	56	2,650	50	3,935	56
Indirect costs	2,703	82	2,209	59	1,657	53	3,882	58	2,944	44	2,641	50	3,053	44
Total	3,280	100	3,773	100	3,117	100	6,701	100	6,620	100	5,291	100	6,988	100
Total with ESP or oxidation			5,748[d]		4,122[e]									
Total with scrubbers	15,122		17,590[d]		15,964[e]		18,543		18,462		17,133		18,830	
Lifetime revenue requirements														
Total	97,758		96,527		78,072		175,765				131,224		167,942	
Discounted total[f]	33,612		32,802		26,513		62,053				45,382		59,099	

a. Basic limestone scrubber capital investment is 36,368 k$; annual revenue requirements are 11,842 k$ (22).
b. Includes 9,614 k$ for ESP units.
c. Includes 2,303 k$ for air-oxidation scrubber modifications.
d. Includes 1,975 k$ for ESP units.
e. Includes 1,005 k$ for air-oxidation scrubber operation.
f. Discounted at 11.6% to initial year.

Important elements in the relative capital cost ranking are pond construction and the amount of equipment required to dewater and blend the wastes and additives. In the sludge - flyash blending and gypsum processes additional equipment is also required to produce dry flyash or highly oxidized sludge. Land costs, at the $3500/acre used, and mobile equipment costs are important but not major capital cost elements and are also partially counteracting.

Pond construction cost is considerably greater than the offsetting equipment simplification and is largely responsible for the low ranking of the untreated-sludge ponding alternative. The Dravo ponding option combines both additional equipment requirements and ponding. Use of a small pond and landfill disposal considerably improves the Dravo landfill alternative ranking, making it similar in capital cost to the other chemical-fixation processes.

The low ranking of the sludge - flyash blending process, which combines low equipment costs with low land requirements, is largely a result of the ESP units, which account for over half of the total capital costs, excluding scrubbing.

The gypsum process combines several favorable elements. Excluding air-oxidation costs it has the lowest direct investment, primarily because of improved dewatering and waste density characteristics and lack of blending requirements. In addition, the additional capital costs for air oxidation are only $2,303,000, much less than pond construction.

Annual revenue requirements, based on first-year, 7000-hour operation, are shown below.

	Disposal only		Scrubbers + disposal	
	k$	Mills/kWh	k$	Mills/kWh
Untreated ponding	3,280	0.94	15,122	4.32
Gypsum + air oxidation	4,122	1.18	15,964	4.56
IUCS	5,291	1.51	17,133	4.90
Sludge - flyash blending + ESP units	5,748	1.64	17,590	5.03
Dravo landfill	6,620	1.89	18,462	5.27
Dravo ponding	6,701	1.91	18,543	5.30
Chemfix	6,988	2.00	18,830	5.38

The ranking based on annual revenue requirements illustrates the effects of conversion and raw material costs. Untreated-sludge ponding, with low conversion costs and no raw material costs, becomes the least-expensive process to operate. Raw material costs composing over half of the direct costs, combined with relatively high conversion costs, result in low ranking for the Dravo and Chemfix processes. The IUCS process, with lower raw material costs, is less affected.

The sludge - flyash blending process compares more favorably with the chemical-treatment processes. ESP costs are approximately a third of the annual revenue requirements for this process but conversion costs are similar to the chemical-treatment processes and it requires no raw materials.

The economic advantages of the gypsum process compared to the other sludge-treatment processes are again evident. Conversion costs are the lowest of the nonponding processes and the additional costs for air oxidation are 0.29 mill/kWh compared to 0.56 mill/kWh for ESP operation and 0.53 and 0.62 mill/kWh for raw materials in the Dravo and Chemfix processes. Combined with low indirect costs resulting from its relatively low capital investment, the gypsum process has the smallest annual revenue requirements of all the alternatives evaluated except ponding.

CONCLUSIONS

The gypsum process has a large advantage over the sludge - flyash blending process in capital investment and a smaller advantage in annual revenue requirements. This is true for the base-case conditions and, to only slightly greater or lesser degree, for all of the case variations studied. The advantage is, in general, a result of the process chemistry, the additional processing steps required for the sludge - flyash blending process, and the superior dewatering and bulk density characteristics of the gypsum waste. The advantage of the gypsum process is enhanced when costs for ESP units and air oxidation are included in the waste disposal process costs.

The sludge - flyash blending process requires equipment for storing and metering the flyash and for mixing it with the dewatered sludge which is not required for the gypsum process. Equipment size is smaller for the sludge - flyash blending process in some respects because flyash does not enter the dewatering process, but this is counteracted by its poorer dewatering characteristics. In addition, the stoichiometry of the basic limestone scrubbing system results in larger amounts of unreacted limestone in the waste compared to the air-oxidation process. The overall result is a 50 to 90% larger major-equipment cost (depending on the case variation) for the sludge - flyash blending process. These higher equipment costs are a major element in the capital investment and annual revenue requirement cost differences between the two processes.

The gypsum process has a further advantage in the smaller weight and volume of waste generated. Although 25 weight percent more sulfur-salt waste is generated in the gypsum process, because of the additional oxidation and hydrated water, this is more than compensated for at base-case stoichiometry conditions by lower quantities of unreacted limestone and water in the waste. Consequently the total weight of waste produced is slightly reduced and the total volume substantially reduced. This has a direct effect on land requirements. It has a less proportional effect on disposal costs; mobile equipment and labor requirements cannot vary continuously with waste quantities because of the incremental nature of the costing units. In general, the gypsum process is also more economical in elements related to the volume of waste generated but the effects of these costs are less important in the cost relationship between the two processes than the effects of major-equipment costs.

BASE CASE

Capital investment for the sludge - flyash blending process is 17.2 \$/kW for the disposal system and 36.4 \$/kW for the system with ESP capital investment included. Capital investment for the gypsum process is 10.8 \$/kW for the disposal system and 15.4 \$/kW for the system including air-oxidation capital investment. Most of the difference, other than the large difference between ESP and air-oxidation costs, is a result of major-equipment costs of 4.0 \$/kW for the sludge - flyash blending process and 2.4 \$/kW for the gypsum process. Thickener costs, which are about half of the equipment costs in dewatering, are much greater for the poorly settling sulfite-rich sludge of the sludge - flyash blending process, more than counteracting the larger costs for combined flyash - sulfate sludge dewatering in the gypsum process.

In addition, about a third of the sludge - flyash blending equipment costs are for flyash handling and blending which are not used in the gypsum process. Overall major process equipment costs are nearly 70% larger for the sludge - flyash blending process than for the gypsum process because of larger thickener requirements and flyash handling and blending requirements.

In comparison, the capital investment cost advantages of the gypsum process related to its higher bulk density are relatively minor. Equipment costs for mobile equipment are much less than process equipment costs and the same number of loaders, trucks, and landfill earthmoving machines is required for both processes. The smaller sizes of the equipment in the gypsum process result in a relatively minor cost reduction.

In general, for the base-case conditions, capital investment is higher for the sludge - flyash blending process because of higher thickener costs and because flyash handling and mixing equipment, not required for the gypsum process, is needed. Relatively minor mobile equipment and land costs contribute to the cost differences. In comparing total capital costs, the sludge - flyash blending process is further handicapped by high ESP costs compared to air-oxidation capital investment costs.

Annual revenue requirements for the two base cases are 1.08 mills/kWh for the sludge - flyash blending process and 0.89 mill/kWh for the gypsum process. Direct costs, consisting entirely of conversion costs, are primarily for plant and mobile equipment operating labor and supervision for both processes. The labor and supervision costs are 32% of the sludge - flyash blending process annual revenue requirements and 38% of the gypsum process annual revenue requirements. The actual labor and supervision costs are \$1,183,000 for both processes, the smaller volume of gypsum process waste providing no advantage at the base-case conditions because of the incremental nature of operator requirements. Mobile equipment operation involved in transportation and placement of the waste constitutes 63% of the total labor and supervision costs for both processes.

Other direct costs are relatively minor compared to the labor and supervision costs. Landfill operation costs, consisting of land preparation and mobile equipment fuel and maintenance, are 9% of the sludge - flyash blending direct costs and 8% of the gypsum process direct costs. Utility costs, consisting entirely of electricity, are minor for both processes.

Total direct costs are 0.45 mill/kWh for the sludge - flyash blending process and 0.42 mill/kWh for the gypsum process. The remaining difference in annual revenue requirements is indirect costs based on capital investment.

When annual revenue requirements of 0.56 mill/kWh for ESP operation and 0.29 mill/kWh for air oxidation are included, the difference between the annual revenue requirements of the processes is more pronounced, becoming 1.64 mills/kWh for the sludge - flyash blending process and 1.18 mills/kWh for the gypsum process.

CASE VARIATIONS

In the range of premise changes used in the case variations the gypsum process remains less costly than the sludge - flyash blending process in both capital investment and annual revenue requirements. The gypsum process capital costs are approximately three-fifths as large as the sludge - flyash blending process capital costs and revenue requirements are approximately four-fifths as large for all case variations. Some case variations produce large to moderate changes in disposal costs for both processes, as shown in Tables 28 and 29. These are those in which the cost areas affected involve process equipment and operating labor and supervision, such as plant size, fuel composition, and distance to the disposal site. Case variations producing large changes in land and mobile equipment costs have less effect on overall costs because of the relatively small portion of the overall costs that these elements represent.

Power Plant Size

Power plant size in the 200-MW to 1500-MW range evaluated has the largest effect on both capital investment and annual revenue requirements. The differences, particularly large in capital investment, are the result of economics of scale, both in equipment and manpower requirements. The differences in capital investment are primarily a result of lower increases in both process and mobile equipment costs relative to power output increases. Similarly, annual revenue requirement differences are primarily a result of lower increases in both process and solids disposal labor and supervision, relative to power output increases.

Most significantly, the cost relationships between the two processes are not affected by the disposal-cost variations with size. The gypsum process remains a considerably less costly process at all three power plant sizes. Capital investment for the gypsum process increases about

TABLE 28. EFFECT OF CASE VARIATIONS ON TOTAL CAPITAL INVESTMENT AND ANNUAL REVENUE REQUIREMENTS - SLUDGE - FLYASH BLENDING

	Percent change from base case	
Variation from base case[a]	Capital investment	Revenue requirements
200 MW	-29	-27
1500 MW	112	84
Existing, 25-yr remaining life	-1	2
Existing, 20-yr remaining life	-3	3
Existing, 15-yr remaining life	-4	6
2% S in coal	-15	-15
5% S in coal	17	12
12% ash in coal	-8	-4
20% ash in coal	8	4
Lime scrubbing process	-5	-3
5 mi to disposal	4	18
10 mi to disposal	8	30
7000 hr/yr operating profile	4	1
200 MW, 7000 hr/yr operating profile	-27	-26
1500 MW, 7000 hr/yr operating profile	125	86
Sludge - flyash layering	2	2
1.3 stoichiometry	-5	-3

a. Base case: 500-MW new plant with 30-yr life.

TABLE 29. EFFECT OF CASE VARIATIONS ON TOTAL CAPITAL INVESTMENT AND ANNUAL REVENUE REQUIREMENTS - GYPSUM

	Percent change from base case	
Variation from base case[a]	Capital investment	Revenue requirements
200 MW	-26	-20
1500 MW	82	59
Existing, 25-yr remaining life	-4	1
Existing, 20-yr remaining life	-5	1
Existing, 15-yr remaining life	-6	4
2% S in coal	-12	-13
5% S in coal	9	4
12% ash in coal	-7	-3
20% ash in coal	5	3
Lime scrubbing process	-2	0
5 mi to disposal	6	19
10 mi to disposal	11	37
7000 hr/yr operating profile	5	1
200 MW, 7000 hr/yr operating profile	-24	-23
1500 MW, 7000 hr/yr operating profile	96	61

a. Base case: 500-MW new plant with 30-yr life.

two and one-half times with power plant size increase from 200-MW to 1500-MW, while the sludge - flyash blending process increase is about three times. Revenue requirements increase about two times for the gypsum process and about two and one-half times for the sludge - flyash blending process. Overall, however, the gypsum process retains its cost advantage at all power plant sizes evaluated.

The same three power plant sizes were also evaluated using a constant-load operating schedule of 7,000 hr/yr over the power plant life, resulting in a 210,000-hour lifetime operating schedule instead of 127,500 hours. The result is to proportionally increase land requirements, based on the additional amount of waste produced, with minor increases in capital costs, insignificant increases in first-year annual revenue requirements, and no change in the relative cost relationships of the two processes.

Lifetime revenue requirements also show the gypsum process to the same advantage over the sludge - flyash blending process. The first-year annual revenue requirements of the gypsum process are 83% of the first-year annual revenue requirements of the sludge - flyash blending process. For the lifetime revenue requirements they are 80% of the sludge - flyash blending process lifetime revenue requirements.

Remaining Life

Remaining power plant lives of 25, 20, and 15 years were compared to the base-case 30-year remaining life. Land requirements are the only large capital investment changes and these have little effect on the total capital investment, which decreases 4% and 6%, respectively, for the sludge - flyash blending and gypsum processes as the plant remaining life decreases from 30 to 15 years. First-year annual revenue requirements are marginally increased by indirect costs related to the accelerated depreciation rate.

Sulfur in Coal

Coal sulfur contents of 2% and 5%, compared to the base-case 3.5%, have a considerable effect on both capital investment and annual revenue requirements of both processes. Coal sulfur increase from 2% to 5% increases capital investment for the sludge - flyash blending process by 37% and increases capital investment for the gypsum process by 23%. The capital investment cost differences are a result of changes in process equipment size, with lesser effects from changes in mobile equipment and land costs. Annual revenue requirements increase 33% in the sludge - flyash blending process and 20% in the gypsum process for the same coal sulfur increases, primarily because of conversion cost increases, particularly disposal labor and supervision costs.

Ash in Coal

Ash content of coal has an effect on both capital investment and revenue requirements similar to the effect of sulfur, and for the same reasons. The sludge - flyash blending process, with a larger proportion of the process equipment involved in flyash processing, has a proportionally larger increase in capital costs with increasing ash content than the gypsum process. Revenue requirements for the two processes increase moderately, by about 9% for the sludge - flyash blending process and 6% for the gypsum process as coal ash content increases from 12% to 20%.

Lime Versus Limestone

The use of lime instead of limestone as the absorbent has a much larger effect on the sludge - flyash blending process than it had on the gypsum process because of the larger improvement in stoichiometry for the sludge - flyash blending process. Both process equipment and land costs were reduced for this process while there was no significant corresponding decrease for the gypsum process. The result is a 5% decrease in capital investment for the sludge - flyash blending process and only a 2% decrease for the gypsum process. The magnitude of these improvements, however, does not greatly effect the cost relationships of the two processes. Changes in annual revenue requirements were also larger for the sludge - flyash blending process and insignificant for the gypsum process, again with marginal effect on the cost relationships of the two processes.

Distance to Disposal Site

Distance to disposal site was evaluated at distances of 5 and 10 miles compared to 1 mile for the base case. This case variation essentially evaluates trucking costs, the only cost affected, in relation to total disposal costs. The increase in capital investment, consisting of additional trucks, is slight, 4% at 5 miles and 8% at 10 miles for the sludge - flyash blending process, and 6% at 5 miles and 11% at 10 miles for the gypsum process with a larger proportion of its equipment in mobile equipment.

Annual revenue requirements, conversely, have the largest increases of all case variations studied except power plant size. The sludge - flyash blending process has increases of 17% and 30% at 5 and 10 miles, respectively, and the gypsum process has increases of 19% and 37%. The differences are a result of greatly increased landfill labor and supervision costs, which increase 40% and 60% at 5 and 10 miles for each process, and mobile equipment fuel and maintenance costs which increase 230% and 550% at 5 and 10 miles for both processes.

The results indicate that transportation costs, if conducted by trucking, are a major consideration in waste disposal if the distances are more than nominal.

Sludge - Flyash Layering

Separate transportation of flyash and dewatered sludge to the disposal site is 2% higher in both capital investment and annual revenue requirements. Process equipment costs are reduced only 2% by elimination of the blending process while mobile equipment costs are increased 30%, producing the 2% increase in capital investment. Landfill operations, primarily mobile equipment fuel and maintenance, account for most of the annual revenue requirement increase.

Sludge - Flyash Blending 1.3 Stoichiometry

This case variation, which has the effect of reducing the quantity of sludge by eliminating about 6700 lb/hr of unreacted limestone from the waste stream, reduces capital investment by 5% because of smaller process equipment size. Annual revenue requirements are reduced 3% because of reduced mobile equipment operating costs. Neither mobile equipment capital investment nor process and landfill labor and supervision costs are reduced.

RECOMMENDATIONS

The results of the two waste disposal economic studies completed by TVA provide a basis of comparison for several disposal alternatives and establish factors having major influences on cost relationships of the processes. Many of these factors are continually changing, however. The two processes evaluated in this report are still in a development stage; chemical-treatment processes are still evolving. Refinements in process technology and changes in raw material requirements could significantly alter the cost relationship of the processes. In addition, regulations affecting disposal procedures could change the overall costs of landfill and ponding operations as well as promote process-specific waste characteristics such as permeability to greater cost significance.

These factors create a need for periodic updating of economic information on waste disposal methods. Current experimental and operating data, particularly on air-oxidation and dewatering technology, should be incorporated into future studies. Vendor modifications to chemical-treatment processes should also be included. The effects of anticipated solid waste disposal regulations should be included in disposal costs and related to process-specific waste characteristics.

REFERENCES

1. Laseke, B. A., Jr. EPA Utility FGD Survey: December 1977-January 1978. EPA-600/7-78-051a, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, 1978. (NTIS PB 279 011)

2. Jones, J. W. Research and Development for Control of Waste Water Pollution from Flue Gas Cleaning Systems. In: Proceedings of the Symposium on Flue Gas Desulfurization, New Orleans, Louisiana. March 1976, Volume II. EPA-600/2-76-136b, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, 1976. pp. 579-604. (NTIS PB 262 722)

3. Barrier, J. W., H. L. Faucett, and L. J. Henson. Economics of Disposal of Lime/Limestone Scrubbing Wastes: Untreated and Chemically Treated Wastes. Bull. Y-123, TVA Office of Agricultural and Chemical Development, Muscle Shoals, Alabama; EPA-600/7-78-023a, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, 1978. (NTIS PB 281 391)

4. Leo, P. P., and J. Rossoff. Control of Waste and Water Pollution from Power Plant Flue Gas Cleaning Systems: First Annual R&D Report. EPA-600/7-76-018, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, 1976. (NTIS PB 259 211)

5. Fling, R. B., W. M. Graven, F. D. Hess, P. P. Leo, R. C. Rossi, and J. Rossoff. Disposal of Flue Gas Cleaning Wastes: EPA Shawnee Field Evaluation - Initial Report. EPA-600/2-76-070, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, 1976. (NTIS PB 251 876)

6. Rossoff, J., and R. C. Rossi. Disposal of Byproducts from Nonregenerable Flue Gas Desulfurization Systems: Inital Report. EPA-650/2-74-037a, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, 1974. (NTIS PB 237 114)

7. Leo, P. P., R. B. Fling, and J. Rossoff. Flue Gas Desulfurization Waste Disposal Study at the Shawnee Power Station. In: Proceedings of the Symposium on Flue Gas Desulfurization, Hollywood, Florida, November 1977 (Volume II), F. A. Ayer, ed., EPA-600/7-78-058b, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, 1978. pp. 496-536. (NTIS PB 282 091)

8. Kelso, T. M. Progress Reports of Plant Operations Section of Emission Control Development Projects, Administrative Files. Tennessee Valley Authority, Muscle Shoals, Alabama, November-December 1976 and January-February 1977.

9. Borgwardt, R. H. *Sludge Oxidation in Limestone FGD Scrubbers*. EPA-600/7-77-061, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, 1977. (NTIS PB 268 525)

10. *Hydroelectric Power Evaluation, FPC P-35 (1968) and Supplement No. 1, FPC P-38*. Federal Energy Regulatory Commission, U.S. Government Printing Office, Washington, D.C., 1969.

11. *Standards of Performance for New Stationary Sources*. U.S. Environmental Protection Agency, Federal Register, 36(247), Part II, December 23, 1971.

12. *Generation - 1977 Fossil Boiler Survey*. Electr. World, 187(5): 35-38, March 1, 1977.

13. Slack, A. V., G. G. McGlamery, and H. L. Falkenberry. *Economic Factors in Recovery of Sulfur Dioxide from Power Plant Stack Gas*. J. Air Pollut. Control Assoc., 21(1):9-15, January 1971.

14. *Steam-Electric Construction Cost and Annual Production Expenses: Twenty-Fourth Annual Supplement - 1971*. Federal Energy Regulatory Commission, U.S. Governm[illegible]rinting Office, Washington, D.C., 1973.

15. Monthly progress report of Bechtel Corporation for EPA Alkali Scrubbing Test Facility - TVA Shawnee Power Plant. Report period March 1-31, 1977, Paducah, Kentucky, May 2, 1977.

16. Peters, M. S., and K. D. Timmerhaus. *Plant Design and Economics for Chemical Engineers*. McGraw-Hill, New York, 1968.

17. Guthrie, K. M. *Capital Cost Estimating*. Chem. Eng., 76(6):114-142, March 24, 1969.

18. Popper, Herbert. *Modern Cost Engineering Technique*. McGraw-Hill, New York, 1970.

19. McGlamery, G. G., R. L. Torstrick, W. J. Broadfoot, J. P. Simpson, L. J. Henson, S. V. Tomlinson, and J. F. Young. *Detailed Cost Estimates for Advanced Effluent Desulfurization Processes*. Bull. Y-90, TVA Office of Agricultural and Chemical Development, Muscle Shoals, Alabama; EPA-600/2-75-006, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, 1975. (NTIS PB 242 541)

20. *Chemical Engineers Handbook*. 4th Ed., R. H. Perry and C. H. Chilton, eds., McGraw-Hill, New York, 1963.

21. The Richardson Rapid System. Vol. 1, 3, 4, Richardson Engineering Services, Inc., Solano Beach, California, 1976.

22. Torstrick, R. L., L. J. Henson, and S. V. Tomlinson. Economic Evaluation Techniques, Results, and Computer Modeling for Flue Gas Desulfurization. In: Proceedings of the Symposium on Flue Gas Desulfurization, Hollywood, Florida, November 1977 (Volume I), F. A. Ayer, ed., EPA-600/7-78-058a, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, 1978. pp. 118-168. (NTIS PB 282 090)

23. Economic Indicators. Chem. Eng., Vol. 81-83, 1974-1976.

24. Selected Ratios for Privately Owned Electric Utilities - Classes A and B. Federal Energy Regulatory Commission, FPC News, 7(40), October 4, 1974.

APPENDIX A

TOTAL CAPITAL INVESTMENT AND ANNUAL REVENUE REQUIREMENT TABLES - ALL PROCESSES AND CASE VARIATIONS

TABLE A-1. SLUDGE BLENDING[a]

TOTAL CAPITAL INVESTMENT - PROCESS EQUIPMENT AND INSTALLATION ANALYSIS

(Base case)

	Total, k$	Percent of direct investment	Percent of total capital investment
Process equipment	1,985	50.2	23.1
Piping and insulation	139	3.5	1.6
Foundation and structural	242	6.1	2.8
Excavation, site preparation, roads and railroads	53	1.3	0.6
Electrical	345	8.7	4.0
Instrumentation	56	1.5	0.7
Buildings	504	12.7	5.8
Subtotal	3,324	84.0	38.6
Services and miscellaneous	50	1.3	0.6
Subtotal excluding trucks and equipment	3,374	85.3	39.2
Trucks and earthmoving equipment	581	14.7	6.8
Subtotal direct investment	3,955	100.0	46.0
Engineering design and supervision	334	8.8	3.9
Architect and engineering contractor	83	2.1	0.9
Construction expense	686	17.2	8.0
Contractor fees	273	6.9	3.2
Subtotal	5,331	135.0	62.0
Contingency	1,066	27.0	12.3
Subtotal fixed investment	6,397	162.0	74.3
Allowance for startup and modifications	582	14.6	6.8
Interest during construction	768	19.4	8.9
Subtotal capital investment	7,747	196.0	90.0
Land	536	13.9	6.3
Working capital	322	8.1	3.7
Total capital investment	8,605	218.0	100.0

---

[a] Basis

New 500-MW plant (30-yr life); 409 klb/hr (15% solids) sludge, 54 klb/hr dry flyash.

Midwest plant location; average basis for scaling, mid-1979.

Coal analysis (by wt): 3.5% S (dry basis), 16% ash.

Flyash removed with ESP. Both removed to meet NSPS. Limestone process with 1.5 stoichiometry based on SO_2 removed. Landfill disposal, 153 acres, 1 mi from scrubber facilities, 74% solids.

TABLE A-2. SLUDGE - FLYASH BLENDING[a]

TOTAL ANNUAL REVENUE REQUIREMENTS - REGULATED UTILITY ECONOMICS

(Base case)

	Annual quantity	Unit cost, $	Total annual revenue requirements, $	Percent of total annual revenue requirements
Direct costs				
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50/man-hr	438,000	11.6
Solids disposal equipment	43,800 man-hr	17.00/man-hr	744,600	19.7
Maintenance--plant labor and supervision, 4% of direct investment			158,200	4.2
Landfill operation				
Land preparation			8,700	0.2
Trucks (fuel and maintenance)	548,720 tons	0.06/ton	32,900	0.9
Earthmoving equipment (fuel and maintenance)	548,720 tons	0.16/ton	87,800	2.3
Electricity	2,652,800 kWh	0.029/kWh	76,900	2.0
Analyses	1,000 hr	17.00/hr	17,000	0.5
Subtotal conversion costs			1,564,100	41.4
Subtotal direct costs			1,564,100	41.4
Indirect costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total capital investment less land and working capital			606,600	16.0
Average cost of capital and taxes at 8.6% of total capital investment			740,000	19.6
Overhead				
Plant, 50% of conversion costs less utilities			743,600	19.7
Administrative, 10% of operating labor			118,300	3.3
Subtotal indirect costs			2,208,500	58.6
Total annual revenue requirements			3,772,600	100.0

	$/dry ton	$/wet ton	mills/kWh
Equivalent unit revenue requirements	9.29	6.87	1.08

---

a. Basis

Remaining plant life, 30 yr.
Coal burned, 429 klb/hr, 9,000 Btu/kWh, 10,500 Btu/lb.
Power plant on-stream time, 7,000 hr/yr.
Total capital investment, $8,605,000.
Midwest plant location, mid-1980 operating costs.

TABLE A-3. SLUDGE BLENDING[a]

TOTAL CAPITAL INVESTMENT - PROCESS EQUIPMENT AND INSTALLATION ANALYSIS

(Variation from base case: 200 MW)

	Total, k$	Percent of direct investment	Percent of total capital investment
Process equipment	1,211	42.9	19.8
Piping and insulation	117	4.1	1.9
Foundation and structural	122	4.3	2.0
Excavation, site preparation, roads and railroads	44	1.6	0.8
Electrical	284	10.1	4.6
Instrumentation	52	1.9	0.8
Buildings	504	17.9	8.2
Subtotal	2,334	82.8	38.1
Services and miscellaneous	35	1.2	0.6
Subtotal excluding trucks and equipment	2,369	84.0	38.7
Trucks and earthmoving equipment	451	16.0	7.3
Subtotal direct investment	2,820	100.0	46.0
Engineering design and supervision	288	10.2	4.7
Architect and engineering contractor	72	2.6	1.2
Construction expense	511	18.1	8.4
Contractor fees	211	7.5	3.4
Subtotal	3,902	138.4	63.7
Contingency	780	27.6	12.7
Subtotal fixed investment	4,682	166.0	76.4
Allowance for startup and modifications	423	15.1	6.9
Interest during construction	562	19.9	9.2
Subtotal capital investment	5,667	201.0	92.5
Land	221	7.8	3.6
Working capital	238	8.4	3.9
Total capital investment	6,126	217.2	100.0

---

[a] Basis

New 200-MW plant (30-yr life); 167 klb/hr (15% solids) sludge, 22 klb/hr dry flyash.

Midwest plant location; average basis for scaling, mid-1979.

Coal analysis (by wt): 3.5% S (dry basis), 16% ash.

Flyash removed with ESP. Both removed to meet NSPS. Limestone process with 1.5 stoichiometry based on SO_2 removed. Landfill disposal, 63 acres, 1 mi from scrubber facilities, 74% solids.

TABLE A-4. SLUDGE - FLYASH BLENDING[a]

TOTAL ANNUAL REVENUE REQUIREMENTS - REGULATED UTILITY ECONOMICS

(Variation from base case: 200 MW)

	Annual quantity	Unit cost, $	Total annual revenue requirements, $	Percent of total annual revenue requirements
Direct costs				
Conversion costs				
Operating labor and supervision				
Plant	26,280 man-hr	12.50/man-hr	328,500	11.8
Solids disposal equipment	35,040 man-hr	17.00/man-hr	595,700	21.4
Maintenance--plant labor and supervision, 4% of direct investment			112,800	4.1
Landfill operation				
Land preparation			3,600	0.1
Trucks (fuel and maintenance)	224,375 tons	0.06/ton	13,500	0.5
Earthmoving equipment (fuel and maintenance)	224,375 tons	0.16/ton	35,900	1.3
Electricity	1,788,500 kWh	0.031/kWh	55,400	2.0
Analyses	1,000 hr	17.00/hr	17,000	0.6
Subtotal conversion costs			1,162,400	41.8
Subtotal direct costs			1,162,400	41.8
Indirect costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total capital investment less land and working capital			443,700	16.0
Average cost of capital and taxes at 8.6% of total capital investment			526,800	19.0
Overhead				
Plant, 50% of conversion costs less utilities			553,500	19.9
Administrative, 10% of operating labor			92,400	3.3
Subtotal indirect costs			1,616,400	58.2
Total annual revenue requirements			2,778,800	100.0

	$/dry ton	$/wet ton	mills/kWh
Equivalent unit revenue requirements	16.73	12.39	1.99

---

a. Basis
Remaining plant life, 30 yr.
Coal burned, 175 klb/hr, 9,200 Btu/kWh, 10,500 Btu/lb.
Power plant on-stream time, 7,000 hr/yr.
Total capital investment, $6,126,000.
Midwest plant location, mid-1980 operating costs.

TABLE A-5. SLUDGE BLENDING[a]

TOTAL CAPITAL INVESTMENT - PROCESS EQUIPMENT AND INSTALLATION ANALYSIS

(Variation from base case: 1500 MW)

	Total, k$	Percent of direct investment	Percent of total capital investment
Process equipment	4,152	47.7	22.7
Piping and insulation	214	2.4	1.2
Foundation and structural	1,264	14.5	6.9
Excavation, site preparation, roads and railroads	85	1.0	0.5
Electrical	540	6.2	3.0
Instrumentation	80	0.9	0.4
Buildings	954	11.0	5.2
Subtotal	7,289	83.7	39.9
Services and miscellaneous	109	1.3	0.6
Subtotal excluding trucks and equipment	7,398	85.0	40.5
Trucks and earthmoving equipment	1,307	15.0	7.1
Subtotal direct investment	8,705	100.0	47.6
Engineering design and supervision	472	5.4	2.6
Architect and engineering contractor	118	1.4	0.7
Construction expense	1,316	15.1	7.2
Contractor fees	497	5.7	2.7
Subtotal	11,108	127.6	60.8
Contingency	2,222	25.5	12.1
Subtotal fixed investment	13,330	153.1	72.9
Allowance for startup and modifications	1,202	13.8	6.6
Interest during construction	1,600	18.4	8.7
Subtotal capital investment	16,132	185.3	88.2
Land	1,607	18.5	8.8
Working capital	543	6.2	3.0
Total capital investment	18,282	210.0	100.0

[a] Basis

New 1500-MW plant (30-yr life); 1,228 klb/hr (15% solids) sludge, 163 klb/hr dry flyash.
Midwest plant location; average basis for scaling, mid-1979.
Coal analysis (by wt): 3.5% S (dry basis), 16% ash.
Flyash removed with ESP. Both removed to meet NSPS. Limestone process with 1.5 stoichiometry based on SO_2 removed. Landfill disposal, 459 acres, 1 mi from scrubber facilities, 74% solids.

TABLE A-6. SLUDGE - FLYASH BLENDING[a]

TOTAL ANNUAL REVENUE REQUIREMENTS - REGULATED UTILITY ECONOMICS

(Variation from base case: 1500 MW)

	Annual quantity	Unit cost, $	Total annual revenue requirements, $	Percent of total annual revenue requirements
Direct costs				
Conversion costs				
Operating labor and supervision				
Plant	43,800 man-hr	12.50/man-hr	547,500	8.0
Solids disposal equipment	70,080 man-hr	17.00/man-hr	1,191,400	17.2
Maintenance--plant labor and supervision, 4% of direct investment			348,200	5.0
Landfill operation				
Land preparation			26,000	0.4
Trucks (fuel and maintenance)	1,646,148 tons	0.06/ton	98,800	1.4
Earthmoving equipment (fuel and maintenance)	1,646,148 tons	0.16/ton	263,400	3.8
Electricity	5,994,900 kWh	0.027/kWh	161,900	2.3
Analyses	1,500 hr	17.00/hr	25,500	0.4
Subtotal conversion costs			2,662,700	38.5
Subtotal direct costs			2,662,700	38.5
Indirect costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total capital investment less land and working capital			1,263,100	18.2
Average cost of capital and taxes at 8.6% of total capital investment			1,572,300	22.7
Overhead				
Plant, 50% of conversion costs less utilities			1,250,400	18.1
Administrative, 10% of operating labor			173,900	2.5
Subtotal indirect costs			4,259,700	61.5
Total annual revenue requirements			6,922,400	100.0

	$/dry ton	$/wet ton	mills/kWh
Equivalent unit revenue requirements	5.69	4.20	0.66

---

a. Basis
- Remaining plant life, 30 yr.
- Coal burned, 1,286 klb/hr, 9,000 Btu/kWh, 10,500 Btu/lb.
- Power plant on-stream time, 7,000 hr/yr.
- Total capital investment, $18,282,000.
- Midwest plant location, mid-1980 operating costs.

TABLE A-7. SLUDGE BLENDING[a]

TOTAL CAPITAL INVESTMENT - PROCESS EQUIPMENT AND INSTALLATION ANALYSIS

(Variation from base case: 500 MW, 25-yr remaining life)

	Total, k$	Percent of direct investment	Percent of total capital investment
Process equipment	2,026	50.7	23.8
Piping and insulation	140	3.5	1.6
Foundation and structural	239	6.0	2.8
Excavation, site preparation, roads and railroads	53	1.3	0.6
Electrical	345	8.7	4.0
Instrumentation	56	1.4	0.7
Buildings	504	12.6	5.9
Subtotal	3,363	84.2	39.4
Services and miscellaneous	50	1.2	0.6
Subtotal excluding trucks and equipment	3,413	85.4	40.0
Trucks and earthmoving equipment	581	14.6	6.8
Subtotal direct investment	3,994	100.0	46.8
Engineering design and supervision	334	8.4	3.9
Architect and engineering contractor	83	2.1	1.0
Construction expense	693	17.3	8.1
Contractor fees	275	6.9	3.3
Subtotal	5,379	134.7	63.1
Contingency	1,076	26.9	12.6
Subtotal fixed investment	6,455	161.6	75.7
Allowance for startup and modifications	587	14.7	6.9
Interest during construction	775	19.4	9.1
Subtotal capital investment	7,817	195.7	91.7
Land	389	9.7	4.5
Working capital	322	8.1	3.8
Total capital investment	8,528	213.5	100.0

---

a. Basis

Existing 500-MW plant (25-yr life); 419 klb/hr (15% solids) sludge, 56 klb/hr dry flyash.

Midwest plant location; average basis for scaling, mid-1979.

Coal analysis (by wt): 3.5% S (dry basis), 16% ash.

Flyash removed with ESP. Both removed to meet NSPS. Limestone process with 1.5 stoichiometry based on SO_2 removed. Landfill disposal, 111 acres, 1 mi from scrubber facilities, 74% solids.

TABLE A-8. SLUDGE - FLYASH BLENDING[a]

TOTAL ANNUAL REVENUE REQUIREMENTS - REGULATED UTILITY ECONOMICS

(Variation from base case: 500 MW, 25-yr remaining life)

	Annual quantity	Unit cost, $	Total annual revenue requirements, $	Percent of total annual revenue requirements
Direct costs				
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50/man-hr	438,000	11.4
Solids disposal equipment	43,800 man-hr	17.00/man-hr	744,600	19.3
Maintenance--plant labor and supervision, 4% of direct investment			159,800	4.2
Landfill operation				
Land preparation			7,700	0.2
Trucks (fuel and maintenance)	560,924 tons	0.06/ton	33,700	0.9
Earthmoving equipment (fuel and maintenance)	560,924 tons	0.16/ton	89,700	2.3
Electricity	2,652,800 kWh	0.029/kWh	76,900	2.0
Analyses	1,000 hr	17.00/hr	17,000	0.4
Subtotal conversion costs			1,567,400	40.7
Subtotal direct costs			1,567,400	40.7
Indirect costs				
Capital charges				
Depreciation, interim replacement, and insurance at 8.8% of total capital investment less land and working capital			687,900	17.9
Average cost of capital and taxes at 8.6% of total capital investment			733,400	19.0
Overhead				
Plant, 50% of conversion costs less utilities			745,300	19.3
Administrative, 10% of operating labor			118,300	3.1
Subtotal indirect costs			2,284,900	59.3
Total annual revenue requirements			3,852,300	100.0

	$/dry ton	$/wet ton	mills/kWh
Equivalent unit revenue requirements	9.28	6.87	1.10

---

a. Basis
Remaining plant life, 25 yr.
Coal burned, 438 klb/hr, 9,200 Btu/kWh, 10,500 Btu/lb.
Power plant on-stream time, 7,000 hr/yr.
Total capital investment, $8,528,000.
Midwest plant location, mid-1980 operating costs.

TABLE A-9. SLUDGE BLENDING[a]

TOTAL CAPITAL INVESTMENT - PROCESS EQUIPMENT AND INSTALLATION ANALYSIS

(Variation from base case: 500 MW, 20-yr remaining life)

	Total, k$	Percent of direct investment	Percent of total capital investment
Process equipment	2,026	50.7	24.2
Piping and insulation	140	3.5	1.7
Foundation and structural	239	6.0	2.8
Excavation, site preparation, roads and railroads	53	1.3	0.6
Electrical	345	8.7	4.1
Instrumentation	56	1.4	0.7
Buildings	504	12.6	6.0
Subtotal	3,363	84.2	40.1
Services and miscellaneous	50	1.2	0.6
Subtotal excluding trucks and equipment	3,413	85.4	40.7
Trucks and earthmoving equipment	581	14.6	7.0
Subtotal direct investment	3,994	100.0	47.7
Engineering design and supervision	334	8.4	4.0
Architect and engineering contractor	83	2.1	1.0
Construction expense	693	17.3	8.2
Contractor fees	275	6.9	3.3
Subtotal	5,379	134.7	64.2
Contingency	1,076	26.9	12.8
Subtotal fixed investment	6,455	161.6	77.0
Allowance for startup and modifications	587	14.7	7.0
Interest during construction	775	19.4	9.3
Subtotal capital investment	7,817	195.7	93.3
Land	242	6.1	2.9
Working capital	322	8.0	3.8
Total capital investment	8,381	209.8	100.0

a. Basis

Existing 500-MW plant (20-yr life); 419 klb/hr (15% solids) sludge, 56 klb/hr dry flyash.

Midwest plant location; average basis for scaling, mid-1979.

Coal analysis (by wt): 3.5% S (dry basis), 16% ash.

Flyash removed with ESP. Both removed to meet NSPS. Limestone process with 1.5 stoichiometry based on SO_2 removed. Landfill disposal, 69 acres, 1 mi from scrubber facilities, 74% solids.

TABLE A-10. SLUDGE - FLYASH BLENDING[a]

TOTAL ANNUAL REVENUE REQUIREMENTS - REGULATED UTILITY ECONOMICS

(Variation from base case: 500 MW, 20-yr remaining life)

	Annual quantity	Unit cost, $	Total annual revenue requirements, $	Percent of total annual revenue requirements
Direct costs				
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50/man-hr	438,000	11.3
Solids disposal equipment	43,800 man-hr	17.00/man-hr	744,600	19.2
Maintenance--plant labor and supervision, 4% of direct investment			159,800	4.1
Landfill operation				
Land preparation			6,000	0.2
Trucks (fuel and maintenance)	560,924 tons	0.06/ton	33,700	0.9
Earthmoving equipment (fuel and maintenance)	560,924 tons	0.16/ton	89,700	2.3
Electricity	2,652,800 kWh	0.029/kWh	76,900	2.0
Analyses	1,000 hr	17.00/hr	17,000	0.4
Subtotal conversion costs			1,565,700	40.4
Subtotal direct costs			1,565,700	40.4
Indirect costs				
Capital charges				
Depreciation, interim replacement, and insurance at 9.3% of total capital investment less land and working capital			727,000	18.7
Average cost of capital and taxes at 8.6% of total capital investment			720,800	18.6
Overhead				
Plant, 50% of conversion costs less utilities			744,400	19.2
Administrative, 10% of operating labor			118,300	3.1
Subtotal indirect costs			2,310,500	59.6
Total annual revenue requirements			3,876,200	100.0

	$/dry ton	$/wet ton	mills/kWh
Equivalent unit revenue requirements	9.34	6.91	1.10

---

a. Basis

Remaining plant life, 20 yr.
Coal burned, 436 klb/hr, 9,200 Btu/kWh, 10,500 Btu/lb.
Power plant on-stream time, 7,000 hr/yr.
Total capital investment, $8,381,000.
Midwest plant location, mid-1980 operating costs.

TABLE A-11. SLUDGE BLENDING[a]

TOTAL CAPITAL INVESTMENT - PROCESS EQUIPMENT AND INSTALLATION ANALYSIS

(Variation from base case: 500 MW, 15-yr remaining life)

	Total, k$	Percent of direct investment	Percent of total capital investment
Process equipment	2,026	50.7	24.4
Piping and insulation	140	3.5	1.7
Foundation and structural	239	6.0	2.9
Excavation, site preparation, roads and railroads	53	1.3	0.6
Electrical	345	8.7	4.2
Instrumentation	56	1.4	0.7
Buildings	504	12.6	6.1
Subtotal	3,363	84.2	40.6
Services and miscellaneous	50	1.2	0.6
Subtotal excluding trucks and equipment	3,413	85.4	41.2
Trucks and earthmoving equipment	581	14.6	7.1
Subtotal direct investment	3,994	100.0	48.3
Engineering design and supervision	334	8.4	4.0
Architect and engineering contractor	83	2.1	1.0
Construction expense	693	17.3	8.4
Contractor fees	275	6.9	3.3
Subtotal	5,379	134.7	65.0
Contingency	1,076	26.9	13.0
Subtotal fixed investment	6,455	161.6	78.0
Allowance for startup and modifications	587	14.7	7.1
Interest during construction	775	19.4	9.4
Subtotal capital investment	7,817	195.7	94.5
Land	137	3.5	1.6
Working capital	322	8.0	3.9
Total capital investment	8,276	207.2	100.0

---

a. Basis

Existing 500-MW plant (15-yr life); 419 klb/hr (15% solids) sludge, 56 klb/hr dry flyash.
Midwest plant location; average basis for scaling, mid-1979.
Coal analysis (by wt): 3.5% S (dry basis), 16% ash.
Flyash removed with ESP. Both removed to meet NSPS. Limestone process with 1.5 stoichiometry based on SO_2 removed. Landfill disposal, 39 acres, 1 mi from scrubber facilities, 74% solids.

TABLE A-12. SLUDGE - FLYASH BLENDING[a]

TOTAL ANNUAL REVENUE REQUIREMENTS - REGULATED UTILITY ECONOMICS

(Variation from base case: 500 MW, 15-yr remaining life)

	Annual quantity	Unit cost, $	Total annual revenue requirements, $	Percent of total annual revenue requirements
Direct costs				
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50/man-hr	438,000	11.0
Solids disposal equipment	43,800 man-hr	17.00/man-hr	744,600	18.7
Maintenance--plant labor and supervision, 4% of direct investment			159,800	4.0
Landfill operation				
Land preparation			4,400	0.1
Trucks (fuel and maintenance)	560,924 tons	0.06/ton	33,700	0.8
Earthmoving equipment (fuel and maintenance)	560,924 tons	0.16/ton	89,700	2.3
Electricity	2,652,800 kWh	0.029/kWh	76,900	1.9
Analyses	1,000 hr	17.00/hr	17,000	0.4
Subtotal conversion costs			1,564,100	39.2
Subtotal direct costs			1,564,100	39.2
Indirect costs				
Capital charges				
Depreciation, interim replacement, and insurance at 10.8% of total capital investment less land and working capital			844,200	21.2
Average cost of capital and taxes at 8.6% of total capital investment			711,700	17.9
Overhead				
Plant, 50% of conversion costs less utilities			743,600	18.7
Administrative, 10% of operating labor			118,300	3.0
Subtotal indirect costs			2,417,800	60.8
Total annual revenue requirements			3,981,900	100.0

	$/dry ton	$/wet ton	mills/kWh
Equivalent unit revenue requirements	9.59	7.10	1.14

---

a. Basis
Remaining plant life, 15 yr.
Coal burned, 438 klb/hr, 9,200 Btu/kWh, 10,500 Btu/lb.
Power plant on-stream time, 7,000 hr/yr.
Total capital investment, $8,276,000.
Midwest plant location, mid-1980 operating costs.

TABLE A-13. SLUDGE BLENDING[a]

TOTAL CAPITAL INVESTMENT - PROCESS EQUIPMENT AND INSTALLATION ANALYSIS

(Variation from base case: 2% S)

	Total, k$	Percent of direct investment	Percent of total capital investment
Process equipment	1,532	45.1	20.8
Piping and insulation	140	4.1	1.9
Foundation and structural	236	7.0	3.2
Excavation, site preparation, roads and railroads	44	1.3	0.6
Electrical	325	9.6	4.4
Instrumentation	54	1.6	0.7
Buildings	504	14.8	6.9
Subtotal	2,835	83.5	38.5
Services and miscellaneous	43	1.3	0.6
Subtotal excluding trucks and equipment	2,878	84.8	39.1
Trucks and earthmoving equipment	517	15.2	7.0
Subtotal direct investment	3,395	100.0	46.1
Engineering design and supervision	322	9.5	4.4
Architect and engineering contractor	81	2.4	1.1
Construction expense	601	17.7	8.2
Contractor fees	243	7.4	3.3
Subtotal	4,642	137.0	63.1
Contingency	928	27.1	12.6
Subtotal fixed investment	5,570	164.1	75.7
Allowance for startup and modifications	505	14.9	6.9
Interest during construction	668	20.0	9.1
Subtotal capital investment	6,743	199.0	91.7
Land	340	10.0	4.6
Working capital	273	8.0	3.7
Total capital investment	7,356	217.0	100.0

[a] Basis
New 500-MW plant (30-yr life); 181 klb/hr (15% solids) sludge; 53 klb/hr dry flyash.
Midwest plant location; average basis for scaling, mid-1979.
Coal analysis (by wt): 2% S (dry basis), 16% ash.
Flyash removed with ESP. Both removed to meet NSPS. Limestone process with 1.5 stoichiometry based on SO_2 removed. Landfill disposal, 97 acres, 1 mi from scrubber facilities, 82% solids.

TABLE A-14. SLUDGE - FLYASH BLENDING[a]

TOTAL ANNUAL REVENUE REQUIREMENTS - REGULATED UTILITY ECONOMICS

(Variation from base case: 2% S)

	Annual quantity	Unit cost, $	Total annual revenue requirements, $	Percent of total annual revenue requirements
Direct costs				
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50/man-hr	438,000	13.6
Solids disposal equipment	35,040 man-hr	17.00/man-hr	595,700	18.5
Maintenance--plant labor and supervision, 4% of direct investment			135,800	4.2
Landfill operation				
Land preparation			5,400	0.2
Trucks (fuel and maintenance)	345,153 tons	0.06/ton	20,700	0.6
Earthmoving equipment (fuel and maintenance)	345,153 tons	0.16/ton	55,200	1.7
Electricity	2,015,700 kWh	0.029/kWh	58,500	1.8
Analyses	1,000 hr	17.00/hr	17,000	0.5
Subtotal conversion costs			1,326,300	41.1
Subtotal direct costs			1,326,300	41.1
Indirect costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total capital investment less land and working capital			528,000	16.4
Average cost of capital and taxes at 8.6% of total capital investment			632,600	19.6
Overhead				
Plant, 50% of conversion costs less utilities			633,900	19.7
Administrative, 10% of operating labor			103,400	3.2
Subtotal indirect costs			1,897,900	58.9
Total annual revenue requirements			3,224,200	100.0

	$/dry ton	$/wet ton	mills/kWh
Equivalent unit revenue requirements	11.40	9.34	0.92

---

a. Basis
Remaining plant life, 30 yr.
Coal burned, 421 klb/hr, 9,000 Btu/kWh, 10,700 Btu/lb.
Power plant on-stream time, 7,000 hr/yr.
Total capital investment, $7,356,000.
Midwest plant location, mid-1980 operating costs.

TABLE A-15. SLUDGE BLENDING[a]

TOTAL CAPITAL INVESTMENT - PROCESS EQUIPMENT AND INSTALLATION ANALYSIS

(Variation from base case: 5% S)

	Total, k$	Percent of direct investment	Percent of total capital investment
Process equipment	2,465	53.3	24.5
Piping and insulation	151	3.3	1.5
Foundation and structural	248	5.4	2.4
Excavation, site preparation, roads and railroads	62	1.3	0.6
Electrical	380	8.2	3.8
Instrumentation	63	1.3	0.6
Buildings	504	10.9	5.0
Subtotal	3,873	83.7	38.4
Services and miscellaneous	58	1.3	0.6
Subtotal excluding trucks and equipment	3,931	85.0	39.0
Trucks and earthmoving equipment	698	15.0	6.9
Subtotal direct investment	4,629	100.0	45.9
Engineering design and supervision	369	8.0	3.7
Architect and engineering contractor	92	2.0	0.9
Construction expense	779	16.7	7.7
Contractor fees	308	6.7	3.1
Subtotal	6,177	133.4	61.3
Contingency	1,235	26.7	12.3
Subtotal fixed investment	7,412	160.1	73.6
Allowance for startup and modifications	671	14.5	6.7
Interest during construction	889	19.2	8.8
Subtotal capital investment	8,972	193.8	89.1
Land	735	15.9	7.3
Working capital	366	7.9	3.6
Total capital investment	10,073	217.6	100.0

---

[a] Basis

New 500-MW plant (30-yr life); 638 klb/hr (15% solids) sludge, 55 klb/hr dry flyash.

Midwest plant location; average basis for scaling, mid-1979.

Coal analysis (by wt): 5% S (dry basis), 16% ash.

Flyash removed with ESP. Both removed to meet NSPS. Limestone process with 1.5 stoichiometry based on SO_2 removed. Landfill disposal, 210 acres, 1 mi from scrubber facilities, 71% solids.

TABLE A-16. SLUDGE - FLYASH BLENDING[a]

TOTAL ANNUAL REVENUE REQUIREMENTS - REGULATED UTILITY ECONOMICS

(Variation from base case: coal with 5% S)

	Annual quantity	Unit cost, $	Total annual revenue requirements, $	Percent of total annual revenue requirements
Direct costs				
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50/man-hr	438,000	10.2
Solids disposal equipment	52,560 man-hr	17.00/man-hr	893,500	20.9
Maintenance--plant labor and supervision, 4% of direct investment			185,200	4.3
Landfill operation				
Land preparation			11,900	0.3
Trucks (fuel and maintenance)	750,516 tons	0.06/ton	45,000	1.0
Earthmoving equipment (fuel and maintenance)	750,516 tons	0.16/ton	120,100	2.8
Electricity	3,519,600 kWh	0.029/kWh	102,100	2.4
Analyses	1,000 hr	17.00/hr	17,000	0.4
Subtotal conversion costs			1,812,800	42.3
Subtotal direct costs			1,812,800	42.3
Indirect costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total capital investment less land and working capital			660,300	15.4
Average cost of capital and taxes at 8.6% of total capital investment			819,900	19.2
Overhead				
Plant, 50% of conversion costs less utilities			855,400	20.0
Administrative, 10% of operating labor			133,200	3.1
Subtotal indirect costs			2,468,800	57.7
Total annual revenue requirements			4,281,600	100.0

	$/dry ton	$/wet ton	mills/kWh
Equivalent unit revenue requirements	8.03	5.71	1.22

---

a. Basis

Remaining plant life, 30 yr.
Coal burned, 433 klb/hr, 9,000 Btu/kWh, 10,400 Btu/lb.
Power plant on-stream time, 7,000 hr/yr.
Total capital investment, $10,073,000.
Midwest plant location, mid-1980 operating costs.

TABLE A-17. SLUDGE BLENDING[a]

TOTAL CAPITAL INVESTMENT - PROCESS EQUIPMENT AND INSTALLATION ANALYSIS

(Variation from base case: 12% ash)

	Total, k$	Percent of direct investment	Percent of total capital investment
Process equipment	1,788	49.0	22.6
Piping and insulation	139	3.8	1.8
Foundation and structural	184	5.0	2.3
Excavation, site preparation, roads and railroads	52	1.4	0.5
Electrical	306	8.4	3.9
Instrumentation	54	1.5	0.7
Buildings	504	13.8	6.4
Subtotal	3,027	82.9	38.2
Services and miscellaneous	45	1.2	0.6
Subtotal excluding trucks and equipment	3,072	84.1	38.8
Trucks and earthmoving equipment	581	15.9	7.3
Subtotal direct investment	3,653	100.0	46.1
Engineering design and supervision	299	8.2	3.8
Architect and engineering contractor	75	2.1	0.9
Construction expense	635	17.4	8.0
Contractor fees	257	7.0	3.3
Subtotal	4,919	134.7	62.1
Contingency	984	26.9	12.5
Subtotal fixed investment	5,903	161.6	74.6
Allowance for startup and modifications	532	14.5	6.7
Interest during construction	708	19.4	8.9
Subtotal capital investment	7,143	195.5	90.2
Land	459	12.6	5.8
Working capital	315	8.6	4.0
Total capital investment	7,917	216.7	100.0

---

[a] Basis

New 500-MW plant (30-yr life); 381 klb/hr (15% solids) sludge, 38 klb/hr dry flyash.

Midwest plant location; average basis for scaling, mid-1979.

Coal analysis (by wt): 3.5% S (dry basis), 12% ash.

Flyash removed with ESP. Both removed to meet NSPS. Limestone process with 1.5 stoichiometry based on SO_2 removed. Landfill disposal, 131 acres, 1 mi from scrubber facilities, 71% solids.

TABLE A-18. SLUDGE - FLYASH BLENDING[a]

TOTAL ANNUAL REVENUE REQUIREMENTS - REGULATED UTILITY ECONOMICS

(Variation from base case: 12% ash)

	Annual quantity	Unit cost, $	Total annual revenue requirements, $	Percent of total annual revenue requirements
Direct costs				
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50/man-hr	438,000	12.1
Solids disposal equipment	43,800 man-hr	17.00/man-hr	744,600	20.6
Maintenance--plant labor and supervision, 4% of direct investment			146,100	4.0
Landfill operation				
Land preparation			7,500	0.2
Trucks (fuel and maintenance)	468,412 tons	0.06/ton	28,100	0.8
Earthmoving equipment (fuel and maintenance)	468,412 tons	0.16/ton	74,900	2.1
Electricity	2,558,800 kWh	0.029/kWh	74,200	2.0
Analyses	1,000 hr	17.00/hr	17,000	0.5
Subtotal conversion costs			1,530,400	42.3
Subtotal direct costs			1,530,400	42.3
Indirect costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total capital investment less land and working capital			559,300	15.5
Average cost of capital and taxes at 8.6% of total capital investment			680,900	18.8
Overhead				
Plant, 50% of conversion costs less utilities			728,100	20.1
Administrative, 10% of operating labor			118,300	3.3
Subtotal indirect costs			2,086,600	57.7
Total annual revenue requirements			3,617,000	100.0

	$/dry ton	$/wet ton	mills/kWh
Equivalent unit revenue requirements	10.88	7.72	1.03

---

a. Basis

Remaining plant life, 30 yr.
Coal burned, 405 klb/hr, 9,000 Btu/kWh, 11,100 Btu/lb.
Power plant on-stream time, 7,000 hr/yr.
Total capital investment, $7,917,000.
Midwest plant location, mid-1980 operating costs.

TABLE A-19. SLUDGE BLENDING[a]

TOTAL CAPITAL INVESTMENT - PROCESS EQUIPMENT AND INSTALLATION ANALYSIS

(Variation from base case: 20% ash)

	Total, k$	Percent of direct investment	Percent of total capital investment
Process equipment	2,173	50.6	23.4
Piping and insulation	140	3.3	1.5
Foundation and structural	311	7.2	3.3
Excavation, site preparation, roads and railroads	55	1.3	0.6
Electrical	340	7.9	3.6
Instrumentation	56	1.3	0.6
Buildings	504	11.7	5.4
Subtotal	3,579	83.3	38.4
Services and miscellaneous	54	1.3	0.7
Subtotal excluding trucks and equipment	3,633	84.6	39.1
Trucks and earthmoving equipment	665	15.4	7.1
Subtotal direct investment	4,298	100.0	46.2
Engineering design and supervision	345	8.0	3.7
Architect and engineering contractor	86	2.0	0.9
Construction expense	731	17.0	7.9
Contractor fees	291	6.8	3.1
Subtotal	5,751	133.8	61.8
Contingency	1,150	26.8	12.3
Subtotal fixed investment	6,901	160.6	74.1
Allowance for startup and modifications	624	14.5	6.7
Interest during construction	828	19.3	8.9
Subtotal capital investment	8,353	194.4	89.7
Land	627	14.6	6.8
Working capital	329	7.6	3.5
Total capital investment	9,309	216.6	100.0

---

[a] Basis

New 500-MW plant (30-yr life); 441 klb/hr (15% solids) sludge, 72 klb/hr dry flyash.

Midwest plant location; average basis for scaling, mid-1979.

Coal analysis (by wt): 3.5% S (dry basis), 20% ash.

Flyash removed with ESP. Both removed to meet NSPS. Limestone process with 1.5 stoichiometry based on SO_2 removed. Landfill disposal, 179 acres, 1 mi from scrubber facilities, 76% solids.

TABLE A-20. SLUDGE - FLYASH BLENDING[a]

TOTAL ANNUAL REVENUE REQUIREMENTS - REGULATED UTILITY ECONOMICS

(Variation from base case: 20% ash)

	Annual quantity	Unit cost, $	Total annual revenue requirements, $	Percent of total annual revenue requirements
Direct costs				
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50/man-hr	438,000	11.0
Solids disposal equipment	43,800 man-hr	17.00/man-hr	744,600	18.8
Maintenance--plant labor and supervision, 4% of direct investment			171,900	4.3
Landfill operation				
Land preparation			10,200	0.3
Trucks (fuel and maintenance)	638,729 tons	0.06/ton	38,300	1.0
Earthmoving equipment (fuel and maintenance)	638,729 tons	0.16/ton	102,200	2.6
Electricity	3,754,600 kWh	0.029/kWh	108,900	2.7
Analyses	1,000 hr	17.00/hr	17,000	0.4
Subtotal conversion costs			1,631,100	41.1
Subtotal direct costs			1,631,100	41.1
Indirect costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total capital investment less land and working capital			654,000	16.5
Average cost of capital and taxes at 8.6% of total capital investment			800,600	20.2
Overhead				
Plant, 50% of conversion costs less utilities			761,100	19.2
Administrative, 10% of operating labor			118,300	3.0
Subtotal indirect costs			2,334,000	58.9
Total annual revenue requirements			3,965,100	100.0

	$/dry ton	$/wet ton	mills/kWh
Equivalent unit revenue requirements	8.17	6.21	1.13

a. Basis

Remaining plant life, 30 yr.
Coal burned, 455 klb/hr, 9,000 Btu/kWh, 9,900 Btu/lb.
Power plant on-stream time, 7,000 hr/yr.
Total capital investment, $9,309,000.
Midwest plant location, mid-1980 operating costs.

TABLE A-21. SLUDGE BLENDING[a]

TOTAL CAPITAL INVESTMENT - PROCESS EQUIPMENT AND INSTALLATION ANALYSIS

(Variation from base case: lime process)

	Total, k$	Percent of direct investment	Percent of total capital investment
Process equipment	1,838	48.8	22.5
Piping and insulation	127	3.4	1.6
Foundation and structural	232	6.1	2.8
Excavation, site preparation, roads and railroads	49	1.3	0.6
Electrical	334	8.9	4.1
Instrumentation	56	1.5	0.7
Buildings	504	13.4	6.2
Subtotal	3,140	83.3	38.4
Services and miscellaneous	47	1.2	0.6
Subtotal excluding trucks and equipment	3,187	84.6	39.0
Trucks and earthmoving equipment	581	15.4	7.1
Subtotal direct investment	3,768	100.0	46.1
Engineering design and supervision	334	8.9	4.1
Architect and engineering contractor	83	2.2	1.0
Construction expense	654	17.4	8.0
Contractor fees	263	7.0	3.2
Subtotal	5,102	135.4	62.4
Contingency	1,020	27.1	12.5
Subtotal fixed investment	6,122	162.5	74.9
Allowance for startup and modifications	554	14.7	6.8
Interest during construction	735	19.5	9.0
Subtotal capital investment	7,411	196.7	90.6
Land	452	12.0	5.5
Working capital	315	8.3	3.9
Total capital investment	8,178	217.0	100.0

---

a. Basis

New 500-MW plant (30-yr life); 309 klb/hr (10% solids) sludge, 54 klb/hr dry flyash.

Midwest plant location; average basis for scaling, mid-1979.

Coal analysis (by wt): 3.5% S (dry basis), 16% ash.

Flyash removed with ESP. Both removed to meet NSPS. Lime process with 1.1 stoichiometry based on SO_2 removed. Landfill disposal, 129 acres, 1 mi from scrubber facilities, 77% solids.

TABLE A-22. SLUDGE - FLYASH BLENDING[a]

TOTAL ANNUAL REVENUE REQUIREMENTS - REGULATED UTILITY ECONOMICS

(Variation from base case: lime process)

	Annual quantity	Unit cost, $	Total annual revenue requirements, $	Percent of total annual revenue requirements
Direct costs				
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50/man-hr	438,000	12.0
Solids disposal equipment	43,800 man-hr	17.00/man-hr	744,600	20.4
Maintenance--plant labor and supervision, 4% of direct investment			150,700	4.1
Landfill operation				
Land preparation			7,300	0.2
Trucks (fuel and maintenance)	461,185 tons	0.06/ton	27,700	0.8
Earthmoving equipment (fuel and maintenance)	461,185 tons	0.16/ton	73,800	2.0
Electricity	2,055,200 kWh	0.029/kWh	59,600	1.6
Analyses	1,000 hr	17.00/hr	17,000	0.5
Subtotal conversion costs			1,518,700	41.6
Subtotal direct costs			1,518,700	41.6
Indirect costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total capital investment less land and working capital			580,300	15.9
Average cost of capital and taxes at 8.6% of total capital investment			703,300	19.3
Overhead				
Plant, 50% of conversion costs less utilities			729,600	20.0
Administrative, 10% of operating labor			118,300	3.2
Subtotal indirect costs			2,131,500	58.4
Total annual revenue requirements			3,650,200	100.0

	$/dry ton	$/wet ton	mills/kWh
Equivalent unit revenue requirements	10.28	7.91	1.04

---

a. Basis

Remaining plant life, 30 yr.
Coal burned, 429 klb/hr, 9,000 Btu/kWh, 10,500 Btu/lb.
Power plant on-stream time, 7,000 hr/yr.
Total capital investment, $8,178,000.
Midwest plant location, mid-1980 operating costs.

TABLE A-23. SLUDGE BLENDING[a]

TOTAL CAPITAL INVESTMENT - PROCESS EQUIPMENT AND INSTALLATION ANALYSIS

(Variation from base case: 5 mi to disposal)

	Total, k$	Percent of direct investment	Percent of total capital investment
Process equipment	1,985	47.8	22.1
Piping and insulation	140	3.4	1.6
Foundation and structural	242	5.8	2.7
Excavation, site preparation, roads and railroads	53	1.3	0.6
Electrical	345	8.3	3.9
Instrumentation	56	1.4	0.6
Buildings	504	12.1	5.6
Subtotal	3,325	80.1	37.1
Services and miscellaneous	50	1.2	0.5
Subtotal excluding trucks and equipment	3,375	81.3	37.6
Trucks and earthmoving equipment	777	18.7	8.7
Subtotal direct investment	4,152	100.0	46.3
Engineering design and supervision	334	8.1	3.7
Architect and engineering contractor	83	2.0	0.9
Construction expense	686	16.5	0.2
Contractor fees	283	6.8	3.2
Subtotal	5,538	133.4	61.7
Contingency	1,108	26.7	12.3
Subtotal fixed investment	6,646	160.1	74.1
Allowance for startup and modifications	587	14.1	6.5
Interest during construction	798	19.2	8.9
Subtotal capital investment	8,031	193.4	89.5
Land	536	12.9	6.0
Working capital	402	9.7	4.5
Total capital investment	8,969	216.0	100.0

[a] Basis

New 500-MW plant (30-yr life); 409 klb/hr (15% solids) sludge, 54 klb/hr dry flyash.

Midwest plant location; average basis for scaling, mid-1979.

Coal analysis (by wt): 3.5% S (dry basis), 16% ash.

Flyash removed with ESP. Both removed to meet NSPS. Limestone process with 1.5 stoichiometry based on SO_2 removed. Landfill disposal, 153 acres, 5 mi from scrubber facilities, 74% solids.

TABLE A-24. SLUDGE - FLYASH BLENDING[a]

TOTAL ANNUAL REVENUE REQUIREMENTS - REGULATED UTILITY ECONOMICS

(Variation from base case: 5 mi to disposal)

	Annual quantity	Unit cost, $	Total annual revenue requirements, $	Percent of total annual revenue requirements
Direct costs				
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50/man-hr	438,000	9.9
Solids disposal equipment	61,320 man-hr	17.00/man-hr	1,042,400	23.5
Maintenance--plant labor and supervision, 4% of direct investment			166,100	3.8
Landfill operation				
Land preparation			8,700	0.2
Trucks (fuel and maintenance)	548,720 tons	0.20/ton	109,700	2.5
Earthmoving equipment (fuel and maintenance)	548,720 tons	0.16/ton	87,800	2.0
Electricity	2,584,900 kWh	0.029/kWh	75,000	1.7
Analyses	1,000 hr	17.00/hr	17,000	0.4
Subtotal conversion costs			1,944,700	44.0
Subtotal direct costs			1,944,700	44.0
Indirect costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total capital investment less land and working capital			628,800	14.2
Average cost of capital and taxes at 8.6% of total capital investment			771,300	17.4
Overhead				
Plant, 50% of conversion costs less utilities			934,900	21.1
Administrative, 10% of operating labor			145,000	3.3
Subtotal indirect costs			2,480,000	56.0
Total annual revenue requirements			4,424,700	100.0

	$/dry ton	$/wet ton	mills/kWh
Equivalent unit revenue requirements	10.90	8.07	1.26

---

a. Basis
Remaining plant life, 30 yr.
Coal burned, 429 klb/hr, 9,000 Btu/kWh, 10,500 Btu/lb.
Power plant on-stream time, 7,000 hr/yr.
Total capital investment, $8,969,000.
Midwest plant location, mid-1980 operating costs.

TABLE A-25. SLUDGE BLENDING[a]

TOTAL CAPITAL INVESTMENT - PROCESS EQUIPMENT AND INSTALLATION ANALYSIS

(Variation from base case: 10 mi to disposal)

	Total, k$	Percent of direct investment	Percent of total capital investment
Process equipment	1,985	45.5	21.3
Piping and insulation	140	3.2	1.5
Foundation and structural	242	5.5	2.6
Excavation, site preparation, roads and railroads	53	1.2	0.6
Electrical	345	7.9	3.7
Instrumentation	56	1.3	0.6
Buildings	504	11.5	5.3
Subtotal	3,325	76.1	35.6
Services and miscellaneous	50	1.2	0.5
Subtotal excluding trucks and equipment	3,375	77.3	36.2
Trucks and earthmoving equipment	992	22.7	10.6
Subtotal direct investment	4,367	100.0	46.8
Engineering design and supervision	334	7.6	3.6
Architect and engineering contractor	83	1.9	0.9
Construction expense	686	15.7	7.3
Contractor fees	294	6.7	3.1
Subtotal	5,764	131.9	61.8
Contingency	1,153	26.4	12.4
Subtotal fixed investment	6,917	158.3	74.1
Allowance for startup and modifications	593	13.6	6.4
Interest during construction	830	19.0	8.9
Subtotal capital investment	8,340	190.9	89.4
Land	536	12.3	5.8
Working capital	458	10.5	4.9
Total capital investment	9,334	213.7	100.0

[a] Basis

New 500-MW plant (30-yr life); 409 klb/hr (15% solids) sludge; 54 klb/hr dry flyash.

Midwest plant location; average basis for scaling, mid-1979.

Coal analysis (by wt): 3.5% S (dry basis), 16% ash.

Flyash removed with ESP. Both removed to meet NSPS. Limestone process with 1.5 stoichiometry based on SO_2 removed. Landfill disposal, 153 acres, 10 mi from scrubber facilities, 74% solids.

TABLE A-26. SLUDGE - FLYASH BLENDING[a]

TOTAL ANNUAL REVENUE REQUIREMENTS - REGULATED UTILITY ECONOMICS

(Variation from base case: 10 mi to disposal)

	Annual quantity	Unit cost, $	Total annual revenue requirements, $	Percent of total annual revenue requirements
Direct costs				
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50/man-hr	438,000	9.0
Solids disposal equipment	70,080 man-hr	17.00/man-hr	1,191,400	24.3
Maintenance--plant labor and supervision, 4% of direct investment			174,700	3.6
Landfill operation				
Land preparation			8,700	0.2
Trucks (fuel and maintenance)	548,720 tons	0.39/ton	214,000	4.4
Earthmoving equipment (fuel and maintenance)	548,720 tons	0.16/ton	87.800	1.8
Electricity	2,584,900 kWh	0.029/kWh	75,000	1.5
Analyses	1,000 hr	17.00/hr	17,000	0.3
Subtotal conversion costs			2,206,600	45.1
Subtotal direct costs			2,206,600	45.1
Indirect costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total capital investment less land and working capital			653,000	13.4
Average cost of capital and taxes at 8.6% of total capital investment			802,700	16.4
Overhead				
Plant, 50% of conversion costs less utilities			1,065,800	21.8
Administrative, 10% of operating labor			162,900	3.3
Subtotal indirect costs			2,684,400	54.9
Total annual revenue requirements			4,891,000	100.0

	$/dry ton	$/wet ton	mills/kWh
Equivalent unit revenue requirements	12.05	8.92	1.40

---

a. Basis
Remaining plant life, 30 yr.
Coal burned, 429 klb/hr, 9,000 Btu/kWh, 10,500 Btu/lb.
Power plant on-stream time, 7,000 hr/yr.
Total capital investment, $9,334,000.
Midwest plant location, mid-1980 operating costs.

TABLE A-27. SLUDGE BLENDING[a]

TOTAL CAPITAL INVESTMENT - PROCESS EQUIPMENT AND INSTALLATION ANALYSIS

(Variation from base case: 500 MW, 7,000 hr/yr)

	Total, k$	Percent of direct investment	Percent of total capital investment
Process equipment	1,985	50.2	22.2
Piping and insulation	139	3.5	1.6
Foundation and structural	242	6.1	2.7
Excavation, site preparation, roads and railroads	53	1.3	0.6
Electrical	345	8.7	3.8
Instrumentation	56	1.4	0.6
Buildings	504	12.8	5.6
Subtotal	3,324	84.0	37.1
Services and miscellaneous	50	1.3	0.6
Subtotal excluding trucks and equipment	3,374	85.3	37.7
Trucks and earthmoving equipment	581	14.7	6.5
Subtotal direct investment	3,955	100.0	44.2
Engineering design and supervision	334	8.4	3.7
Architect and engineering contractor	83	2.0	0.9
Construction expense	686	17.3	7.7
Contractor fees	273	6.9	3.0
Subtotal	5,331	134.6	59.5
Contingency	1,066	27.0	11.9
Subtotal fixed investment	6,397	161.6	71.4
Allowance for startup and modifications	582	14.7	6.5
Interest during construction	768	19.4	8.6
Subtotal capital investment	7,747	195.7	86.5
Land	886	22.4	9.9
Working capital	322	8.1	3.6
Total capital investment	8,955	226.2	100.0

a. Basis

New 500-MW plant (30-yr life); 409 klb/hr (15% solids), 54 klb/hr dry flyash.

Midwest plant location; average basis for scaling, mid-1979.
Coal analysis (by wt): 3.5% S (dry basis), 16% ash.
Flyash removed by ESP. Both removed to meet NSPS. Limestone process with 1.5 stoichiometry based on SO_2 removed. Landfill disposal, 252 acres, 1 mi from scrubber facilities, 74% solids.

TABLE A-28. SLUDGE - FLYASH BLENDING[a]

TOTAL ANNUAL REVENUE REQUIREMENTS - REGULATED UTILITY ECONOMICS

(Variation from base case: 500 MW, 7,000-hr/yr operating profile)

	Annual quantity	Unit cost, $	Total annual revenue requirements, $	Percent of total annual revenue requirements
Direct costs				
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50/man-hr	438,000	11.5
Solids disposal equipment	43,800 man-hr	17.00/man-hr	744,600	19.6
Maintenance--plant labor and supervision, 4% of direct investment			158,200	4.2
Landfill operation				
Land preparation			8,700	0.2
Trucks (fuel and maintenance)	548,720 tons	0.06/ton	32,900	0.9
Earthmoving equipment (fuel and maintenance)	548,720 tons	0.16/ton	87,800	2.3
Electricity	2,584,900 kWh	0.029/kWh	75,000	2.0
Analyses	1,000 hr	17.00/hr	17,000	0.4
Subtotal conversion costs			1,562,200	41.1
Subtotal direct costs			1,562,200	41.1
Indirect costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total capital investment less land and working capital			606,600	15.9
Average cost of capital and taxes at 8.6% of total capital investment			770,100	20.3
Overhead				
Plant, 50% of conversion costs less utilities			743,600	19.6
Administrative, 10% of operating labor			118,300	3.1
Subtotal indirect costs			2,238,600	58.9
Total annual revenue requirements			3,800,800	100.0

	$/dry ton	$/wet ton	mills/kWh
Equivalent unit revenue requirements	9.76	6.93	1.09

---

a. Basis

Remaining plant life, 30 yr.
Coal burned, 429 klb/hr, 9,000 Btu/kWh, 10,500 Btu/lb.
Power plant on-stream time, 7,000 hr/yr.
Total capital investment, $8,955,000.
Midwest plant location, mid-1980 operating costs.

TABLE A-29. SLUDGE BLENDING[a]

TOTAL CAPITAL INVESTMENT - PROCESS EQUIPMENT AND INSTALLATION ANALYSIS

(Variation from base case: layering)

	Total, k$	Percent of direct investment	Percent of total capital investment
Process equipment	1,947	47.7	22.3
Piping and insulation	140	3.4	1.6
Foundation and structural	238	5.8	2.7
Excavation, site preparation, roads and railroads	53	1.3	0.6
Electrical	345	8.5	3.9
Instrumentation	56	1.4	0.6
Buildings	504	12.3	5.8
Subtotal	3,283	80.4	37.5
Services and miscellaneous	49	1.2	0.6
Subtotal excluding trucks and equipment	3,332	81.6	38.1
Trucks and earthmoving equipment	751	18.4	8.6
Subtotal direct investment	4,083	100.0	46.7
Engineering design and supervision	311	7.6	3.6
Architect and engineering contractor	78	1.9	0.9
Construction expense	679	16.6	7.8
Contractor fees	280	6.9	3.2
Subtotal	5,431	133.0	62.2
Contingency	1,086	26.6	12.4
Subtotal fixed investment	6,517	159.6	74.6
Allowance for startup and modifications	578	14.2	6.6
Interest during construction	782	19.2	8.9
Subtotal capital investment	7,877	193.0	90.1
Land	536	13.1	6.1
Working capital	330	8.1	3.8
Total capital investment	8,743	214.2	100.0

a. Basis

New 500-MW plant (30-yr life); 409 klb/hr (15% solids) sludge, 54 klb/hr dry flyash.
Midwest plant location; average basis for scaling, mid-1979.
Coal analysis (by wt): 3.5% S (dry basis), 16% ash.
Flyash removed with ESP. Both removed to meet NSPS. Limestone process with 1.5 stoichiometry based on SO_2 removed. Landfill disposal, 153 acres, 1 mi from scrubber facilities, 74% solids.

TABLE A-30. SLUDGE - FLYASH BLENDING[a]

TOTAL ANNUAL REVENUE REQUIREMENTS - REGULATED UTILITY ECONOMICS

(Variation from base case: layering)

	Annual quantity	Unit cost, $	Total annual revenue requirements, $	Percent of total annual revenue requirements
Direct costs				
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50/man-hr	438,000	11.3
Solids disposal equipment	43,800 man-hr	17.00/man-hr	744,600	19.3
Maintenance--plant labor and supervision, 4% of direct investment			163,300	4.2
Landfill operation				
Land preparation			8,700	0.2
Trucks (fuel and maintenance)	548,720 tons	0.06/ton	32,900	0.9
Earthmoving equipment (fuel and maintenance)	548,720 tons	0.24/ton	131,700	3.4
Electricity	2,584,900 kWh	0.029/kWh	75,000	1.9
Analyses	1,000 hr	17.00/hr	17,000	0.4
Subtotal conversion costs			1,611,200	41.7
Subtotal direct costs			1,611,200	41.7
Indirect costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total capital investment less land and working capital			616,800	16.0
Average cost of capital and taxes at 8.6% of total capital investment			751,900	19.4
Overhead				
Plant, 50% of conversion costs less utilities			768,100	19.9
Administrative, 10% of operating labor			118,300	3.0
Subtotal indirect costs			2,255,100	58.3
Total annual revenue requirements			3,866,300	100.0

	$/dry ton	$/wet ton	mills/kWh
Equivalent unit revenue requirements	9.54	7.05	1.10

a. Basis
- Remaining plant life, 30 yr.
- Coal burned, 429 klb/hr, 9,000 Btu/kWh, 10,500 Btu/lb.
- Power plant on-stream time, 7,000 hr/yr.
- Total capital investment, $8,743,000.
- Midwest plant location, mid-1980 operating costs.

TABLE A-31. SLUDGE BLENDING[a]

TOTAL CAPITAL INVESTMENT - PROCESS EQUIPMENT AND INSTALLATION ANALYSIS

(Variation from base case: 1.3 limestone stoichiometry)

	Total, k$	Percent of direct investment	Percent of total capital investment
Process equipment	1,771	47.5	21.7
Piping and insulation	139	3.7	1.7
Foundation and structural	238	6.4	2.9
Excavation, site preparation, roads and railroads	51	1.4	0.6
Electrical	344	9.2	4.2
Instrumentation	56	1.5	0.7
Buildings	504	13.5	6.2
Subtotal	3,103	83.2	38.0
Services and miscellaneous	47	1.2	0.6
Subtotal excluding trucks and equipment	3,150	84.4	38.6
Trucks and earthmoving equipment	581	15.6	7.1
Subtotal direct investment	3,731	100.0	45.7
Engineering design and supervision	334	9.0	4.1
Architect and engineering contractor	83	2.2	1.0
Construction expense	648	17.4	8.0
Contractor fees	261	7.0	3.2
Subtotal	5,057	135.6	62.0
Contingency	1,011	27.1	12.4
Subtotal fixed investment	6,068	162.6	74.4
Allowance for startup and modifications	549	14.7	6.7
Interest during construction	728	19.5	8.9
Subtotal capital investment	7,345	196.9	90.0
Land	497	13.3	6.1
Working capital	318	8.5	3.9
Total capital investment	8,160	218.7	100.0

---

[a] Basis

New 500-MW plant (30-yr life); 365 klb/hr (15% solids) sludge, 54 klb/hr dry flyash.

Midwest plant location; average basis for scaling, mid-1979.

Coal analysis (by wt): 3.5% S (dry basis), 16% ash.

Flyash removed with ESP. Both removed to meet NSPS. Limestone process with 1.3 stoichiometry based on SO_2 removed. Landfill disposal, 142 acres, 1 mi from scrubber facilities, 74% solids.

TABLE A-32. SLUDGE - FLYASH BLENDING[a]

TOTAL ANNUAL REVENUE REQUIREMENTS - REGULATED UTILITY ECONOMICS

(Variation from base case: 1.3 limestone stoichiometry)

	Annual quantity	Unit cost, $	Total annual revenue requirements, $	Percent of total annual revenue requirements
Direct costs				
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50/man-hr	438,000	11.9
Solids disposal equipment	43,800 man-hr	17.00/man-hr	744,600	20.3
Maintenance--plant labor and supervision, 4% of direct investment			149,200	4.1
Landfill operation				
Land preparation			8,000	0.2
Trucks (fuel and maintenance)	509,712 tons	0.06/ton	30,600	0.8
Earthmoving equipment (fuel and maintenance)	509,712 tons	0.16/ton	81,600	2.2
Electricity	2,572,500 kWh	0.029/kWh	74,600	2.0
Analyses	1,000 hr	17.00/hr	17,000	0.5
Subtotal conversion costs			1,543,600	42.0
Subtotal direct costs			1,543,600	42.0
Indirect costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total capital investment less land and working capital			575,100	15.7
Average cost of capital and taxes at 8.6% of total capital investment			701,800	19.1
Overhead				
Plant, 50% of conversion costs less utilities			734,500	20.0
Administrative, 10% of operating labor			118,300	3.2
Subtotal indirect costs			2,129,700	58.0
Total annual revenue requirements			3,673,300	100.0

	$/dry ton	$/wet ton	mills/kWh
Equivalent unit revenue requirements	9.73	7.19	1.04

---

a. Basis
Remaining plant life, 30 yr.
Coal burned, 429 klb/hr, 9,000 Btu/kWh, 10,500 Btu/lb.
Power plant on-stream time, 7,000 hr/yr.
Total capital investment, $8,160,000.
Midwest plant location, mid-1980 operating costs.

TABLE A-33. SLUDGE BLENDING[a]

TOTAL CAPITAL INVESTMENT - PROCESS EQUIPMENT AND INSTALLATION ANALYSIS

(Variation from base case: 200 MW, 7,000-hr/yr constant load)

	Total, k$	Percent of direct investment	Percent of total capital investment
Process equipment	1,211	42.9	19.3
Piping and insulation	117	4.2	1.9
Foundation and structural	122	4.3	1.9
Excavation, site preparation, roads and railroads	44	1.6	0.7
Electrical	284	10.1	4.5
Instrumentation	52	1.8	0.8
Buildings	504	17.9	8.0
Subtotal	2,334	82.8	37.2
Services and miscellaneous	35	1.2	0.6
Subtotal excluding trucks and equipment	2,369	84.0	37.8
Trucks and earthmoving equipment	451	16.0	7.2
Subtotal direct investment	2,820	100.0	45.0
Engineering design and supervision	288	10.2	4.6
Architect and engineering contractor	72	2.6	1.1
Construction expense	511	18.1	8.2
Contractor fees	211	7.5	3.4
Subtotal	3,902	138.4	62.3
Contingency	780	27.6	12.4
Subtotal fixed investment	4,682	166.0	74.7
Allowance for startup and modifications	423	15.0	6.7
Interest during construction	562	20.0	9.0
Subtotal capital investment	5,667	201.0	90.4
Land	363	12.9	5.8
Working capital	238	8.4	3.8
Total capital investment	6,268	222.3	100.0

---

[a] Basis

New 200-MW plant (30-yr life); 167 klb/hr (15% solids) sludge, 64 klb/hr dry flyash.
Midwest plant location; average basis for scaling, mid-1979.
Coal analysis (by wt): 3.5% S (dry basis), 16% ash.
Flyash removed with ESP. Both removed to meet NSPS. Limestone process with 1.5 stoichiometry based on SO_2 removed. Landfill disposal, 104 acres, 1 mi from scrubber facilities, 74% solids.

TABLE A-34. SLUDGE - FLYASH BLENDING[a]

TOTAL ANNUAL REVENUE REQUIREMENTS - REGULATED UTILITY ECONOMICS

(Variation from base case: 200 MW, 7,000-hr/yr constant load)

	Annual quantity	Unit cost, $	Total annual revenue requirements, $	Percent of total annual revenue requirements
Direct costs				
Conversion costs				
Operating labor and supervision				
Plant	26,280 man-hr	12.50/man-hr	328,500	11.8
Solids disposal equipment	35,040 man-hr	17.00/man-hr	595,700	21.4
Maintenance--plant labor and supervision, 4% of direct investment			112,800	4.0
Landfill operation				
Land preparation			3,600	0.1
Trucks (fuel and maintenance)	224,375 tons	0.06/ton	13,500	0.5
Earthmoving equipment (fuel and maintenance)	224,375 tons	0.16/ton	35,900	1.3
Electricity	1,788,500 kWh	0.031/kWh	55,400	2.0
Analyses	1,000 hr	17.00/hr	17,000	0.6
Subtotal conversion costs			1,162,400	41.7
Subtotal direct costs			1,162,400	41.7
Indirect costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total capital investment less land and working capital			443,700	15.9
Average cost of capital and taxes at 8.6% of total capital investment			539,000	19.3
Overhead				
Plant, 50% of conversion costs less utilities			553,500	19.8
Administrative, 10% of operating labor			92,400	3.3
Subtotal indirect costs			1,628,600	58.3
Total annual revenue requirements			2,791,000	100.0

	$/dry ton	$/wet ton	mills/kWh
Equivalent unit revenue requirements	16.80	12.44	2.00

---

a. Basis

Remaining plant life, 30 yr.
Coal burned, 175 klb/hr, 9,200 Btu/kWh, 10,500 Btu/lb.
Power plant on-stream time, 7,000 hr/yr.
Total capital investment, $6,268,000.
Midwest plant location, mid-1980 operating costs.

TABLE A-35. SLUDGE BLENDING[a]

TOTAL CAPITAL INVESTMENT - PROCESS EQUIPMENT AND INSTALLATION ANALYSIS

(Variation from base case: 1,500 MW, 7,000-hr/yr constant load)

	Total, k$	Percent of direct investment	Percent of total capital investment
Process equipment	4,152	47.7	21.5
Piping and insulation	214	2.5	1.1
Foundation and structural	1,264	14.5	6.5
Excavation, site preparation, roads and railroads	85	1.0	0.4
Electrical	540	6.2	2.8
Instrumentation	80	0.9	0.4
Buildings	954	11.0	4.9
Subtotal	7,289	83.7	37.7
Services and miscellaneous	109	1.3	0.6
Subtotal excluding trucks and equipment	7,398	85.0	38.3
Trucks and earthmoving equipment	1,307	15.0	6.8
Subtotal direct investment	8,705	100.0	45.1
Engineering design and supervision	472	5.4	2.4
Architect and engineering contractor	118	1.4	0.6
Construction expense	1,316	15.1	6.8
Contractor fees	497	5.7	2.6
Subtotal	11,108	127.6	57.5
Contingency	2,222	25.5	11.5
Subtotal fixed investment	13,330	153.1	69.0
Allowance for startup and modifications	1,202	13.8	6.2
Interest during construction	1,600	18.4	8.3
Subtotal capital investment	16,132	185.3	83.5
Land	2,646	30.4	13.7
Working capital	543	6.2	2.8
Total capital investment	19,321	221.9	100.0

---

[a] Basis

New 1500-MW plant (30-yr life); 1,228 klb/hr (15% solids) sludge, 470 klb/hr dry flyash.

Midwest plant location; average basis for scaling, mid-1979.

Coal analysis (by wt): 3.5% S (dry basis), 16% ash.

Flyash removed with ESP. Both removed to meet NSPS. Limestone process with 1.5 stoichiometry based on SO_2 removed. Landfill disposal, 756 acres, 1 mi from scrubber facilities, 74% solids.

TABLE A-36. SLUDGE - FLYASH BLENDING[a]

TOTAL ANNUAL REVENUE REQUIREMENTS - REGULATED UTILITY ECONOMICS

(Variation from base case: 1,500 MW, 7,000-hr/yr constant load)

	Annual quantity	Unit cost, $	Total annual revenue requirements, $	Percent of total annual revenue requirements
Direct costs				
Conversion costs				
Operating labor and supervision				
Plant	43,800 man-hr	12.50/man-hr	547,500	7.8
Solids disposal equipment	70,080 man-hr	17.00/man-hr	1,191,400	17.0
Maintenance--plant labor and supervision, 4% of direct investment			348,200	5.0
Landfill operation				
Land preparation			26,000	0.4
Trucks (fuel and maintenance)	1,646,148 tons	0.06/ton	98,800	1.4
Earthmoving equipment (fuel and maintenance)	1,646,148 tons	0.16/ton	263,400	3.7
Electricity	5,944,900 kWh	0.027/kWh	161,900	2.3
Analyses	1,500 hr	17.00/hr	25,500	0.4
Subtotal conversion costs			2,662,700	40.0
Subtotal direct costs			2,662,700	40.0
Indirect costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total capital investment less land and working capital			1,263,100	18.0
Average cost of capital and taxes at 8.6% of total capital investment			1,661,600	23.7
Overhead				
Plant, 50% of conversion costs less utilities			1,250,400	17.8
Administrative, 10% of operating labor			173,900	2.5
Subtotal indirect costs			4,349,000	62.0
Total annual revenue requirements			7,011,700	100.0

	$/dry ton	$/wet ton	mills/kWh
Equivalent unit revenue requirements	5.76	4.25	0.67

---

a. Basis
Remaining plant life, 30 yr.
Coal burned, 1,286 klb/hr, 9,000 Btu/kWh, 10,500 Btu/lb.
Power plant on-stream time, 7,000 hr/yr.
Total capital investment, $19,321,000.
Midwest plant location, mid-1980 operating costs.

TABLE A-37. GYPSUM[a]

TOTAL CAPITAL INVESTMENT - PROCESS EQUIPMENT AND INSTALLATION ANALYSIS

(Base case)

	Total, k$	Percent of direct investment	Percent of total capital investment
Process equipment	1,179	49.3	21.7
Piping and insulation	174	7.3	3.2
Foundation and structural	25	1.0	0.5
Excavation, site preparation, roads and railroads	42	1.8	0.8
Electrical	220	9.2	4.1
Instrumentation	52	2.2	1.0
Buildings	174	7.3	3.2
Subtotal	1,866	78.1	34.5
Services and miscellaneous	27	1.1	0.5
Subtotal excluding trucks and equipment	1,893	79.2	35.0
Trucks and earthmoving equipment	498	20.8	9.2
Subtotal direct investment	2,391	100.0	44.2
Engineering design and supervision	195	8.2	3.6
Architect and engineering contractor	48	2.0	0.9
Construction expense	425	17.8	7.9
Contractor fees	186	7.8	3.4
Subtotal	3,245	135.8	60.0
Contingency	649	27.1	12.0
Subtotal fixed investment	3,894	162.9	72.0
Allowance for startup and modifications	340	14.2	6.3
Interest during construction	467	19.5	8.6
Subtotal capital investment	4,701	196.6	86.9
Land	403	16.9	7.5
Working capital	307	12.8	5.6
Total capital investment	5,411	226.3	100.0

---

[a] Basis

New 500-MW plant (30-yr life); 756 klb/hr (15% solids) sludge.
Midwest plant location; average basis for scaling, mid-1979.
Coal analysis (by wt): 3.5% S (dry basis), 16% ash.
Flyash removed with SO_2. Both removed to meet NSPS. Forced-oxidation limestone process with 1.1 stoichiometry based on SO_2 removed. Landfill disposal, 115 acres, 1 mi from scrubber facilities, 80% solids gypsum.

TABLE A-38. GYPSUM[a]

TOTAL ANNUAL REVENUE REQUIREMENTS - REGULATED UTILITY ECONOMICS

(Base case)

	Annual quantity	Unit cost, $	Total annual revenue requirements, $	Percent of total annual revenue requirements
Direct costs				
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50/man-hr	438,000	14.0
Solids disposal equipment	43,800 man-hr	17.00/man-hr	744,600	23.9
Maintenance--plant labor and supervision, 4% of direct investment			95,600	3.1
Landfill operation				
Land preparation			6,600	0.2
Trucks (fuel and maintenance)	496,048 tons	0.06/ton	29,800	1.0
Earthmoving equipment (fuel and maintenance)	496,048 tons	0.16/ton	79,400	2.5
Electricity	1,699,761 kWh	0.029/kWh	49,300	1.6
Analyses	1,000 hr	17.00/hr	17,000	0.5
Subtotal conversion costs			1,460,300	46.8
Subtotal direct costs			1,460,300	46.8
Indirect costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total capital investment less land and working capital			368,100	11.8
Average cost of capital and taxes at 8.6% of total capital investment			465,300	14.9
Overhead				
Plant, 50% of conversion costs less utilities			705,500	22.7
Administrative, 10% of operating labor			118,300	3.8
Subtotal indirect costs			1,657,200	53.2
Total annual revenue requirements			3,117,500	100.0

	$/dry ton	$/wet ton	mills/kWh
Equivalent unit revenue requirements	7.86	6.28	0.89

a. Basis
Remaining plant life, 30 yr.
Coal burned, 429 klb/hr, 9,000 Btu/kWh, 10,500 Btu/lb.
Power plant on-stream time, 7,000 hr/yr.
Total capital investment, $5,411,000.
Midwest plant location, mid-1980 operating costs.

TABLE A-39. GYPSUM[a]

TOTAL CAPITAL INVESTMENT - PROCESS EQUIPMENT AND INSTALLATION ANALYSIS

(Variation from base case: 200 MW)

	Total, k$	Percent of direct investment	Percent of total capital investment
Process equipment	794	44.8	20.1
Piping and insulation	124	7.0	3.1
Foundation and structural	17	1.0	0.4
Excavation, site preparation, roads and railroads	38	2.1	1.0
Electrical	180	10.2	4.5
Instrumentation	44	2.5	1.1
Buildings	174	9.8	4.4
Subtotal	1,371	77.4	34.6
Services and miscellaneous	20	1.1	0.5
Subtotal excluding trucks and equipment	1,391	78.5	35.1
Trucks and earthmoving equipment	381	21.5	9.6
Subtotal direct investment	1,772	100.0	44.7
Engineering design and supervision	172	9.7	4.3
Architect and engineering contractor	43	2.4	1.1
Construction expense	329	18.6	8.4
Contractor fees	148	8.4	3.7
Subtotal	2,464	139.1	62.2
Contingency	493	27.8	12.4
Subtotal fixed investment	2,957	166.9	74.6
Allowance for startup and modifications	258	14.6	6.5
Interest during construction	355	20.0	9.0
Subtotal capital investment	3,570	201.5	90.1
Land	165	9.3	4.2
Working capital	229	12.9	5.7
Total capital investment	3,964	223.7	100.0

---

[a] Basis
New 200-MW plant (30-yr life); 309 klb/hr (15% solids) sludge.
Midwest plant location; average basis for scaling, mid-1979.
Coal analysis (by wt): 3.5% S (dry basis), 16% ash.
Flyash removed with SO_2. Both removed to meet NSPS. Forced-oxidation limestone process with 1.1 stoichiometry based on SO_2 removed. Landfill disposal, 47 acres, 1 mi from scrubber facilities, 80% solids gypsum.

TABLE A-40. GYPSUM[a]

TOTAL ANNUAL REVENUE REQUIREMENTS - REGULATED UTILITY ECONOMICS

(Variation from base case: 200 MW)

	Annual quantity	Unit cost, $	Total annual revenue requirements, $	Percent of total annual revenue requirements
Direct costs				
Conversion costs				
Operating labor and supervision				
Plant	26,280 man-hr	12.50/man-hr	328,500	14.1
Solids disposal equipment	35,040 man-hr	17.00/man-hr	595,700	25.7
Maintenance--plant labor and supervision, 4% of direct investment			70,900	3.0
Landfill operation				
Land preparation			2,700	0.1
Trucks (fuel and maintenance)	202,836 tons	0.06/ton	12,200	0.5
Earthmoving equipment (fuel and maintenance)	202,836 tons	0.16/ton	32,500	1.4
Electricity	725,858 kWh	0.031/kWh	22,500	1.0
Analyses	1,000 hr	17.00/hr	17,000	0.7
Subtotal conversion costs			1,082,000	46.5
Subtotal direct costs			1,082,000	46.5
Indirect costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total capital investment less land and working capital			279,500	12.0
Average cost of capital and taxes at 8.6% of total capital investment			343,000	14.7
Overhead				
Plant, 50% of conversion costs less utilities			529,800	22.8
Administrative, 10% of operating labor			92,400	4.0
Subtotal indirect costs			1,244,700	53.4
Total annual revenue requirements			2,326,700	100.0

	$/dry ton	$/wet ton	mills/kWh
Equivalent unit revenue requirements	14.31	11.44	1.66

---

a. Basis
Remaining plant life, 30 yr.
Coal burned, 175 klb/hr, 9,200 Btu/kWh, 10,500 Btu/lb.
Power plant on-stream time, 7,000 hr/yr.
Total capital investment, $3,988,000.
Midwest plant location, mid-1980 operating costs.

TABLE A-41. GYPSUM[a]

TOTAL CAPITAL INVESTMENT - PROCESS EQUIPMENT AND INSTALLATION ANALYSIS

(Variation from base case: 1500 MW)

	Total, k$	Percent of direct investment	Percent of total capital investment
Process equipment	2,215	51.1	22.4
Piping and insulation	290	6.7	3.0
Foundation and structural	47	1.1	0.5
Excavation, site preparation, roads and railroads	59	1.4	0.6
Electrical	374	8.7	3.8
Instrumentation	55	1.3	0.6
Buildings	294	6.8	3.0
Subtotal	3,334	77.1	33.9
Services and miscellaneous	50	1.1	0.5
Subtotal excluding trucks and equipment	3,384	78.2	34.4
Trucks and earthmoving equipment	942	21.8	9.5
Subtotal direct investment	4,326	100.0	43.9
Engineering design and supervision	264	6.1	2.7
Architect and engineering contractor	66	1.5	0.7
Construction expense	688	15.9	7.0
Contractor fees	292	6.8	3.0
Subtotal	5,636	130.3	57.3
Contingency	1,127	26.0	11.5
Subtotal fixed investment	6,763	156.3	68.8
Allowance for startup and modifications	582	13.5	5.9
Interest during construction	812	18.8	8.3
Subtotal capital investment	8,157	188.6	83.0
Land	1,201	27.7	12.2
Working capital	468	10.8	4.8
Total capital investment	9,826	227.1	100.0

---

a. Basis

New 1500-MW plant (30-yr life); 2,268 klb/hr (15% solids) sludge.
Midwest plant location; average basis for scaling, mid-1979.
Coal analysis (by wt): 3.5% S (dry basis), 16% ash.
Flyash removed with SO_2. Both removed to meet NSPS. Forced-oxidation limestone process with 1.1 stoichiometry based on SO_2 removed. Landfill disposal, 343 acres, 1 mi from scrubber facilities, 80% solids gypsum.

TABLE A-42. GYPSUM[a]

TOTAL ANNUAL REVENUE REQUIREMENTS - REGULATED UTILITY ECONOMICS

(Variation from base case: 1500 MW)

	Annual quantity	Unit cost, $	Total annual revenue requirements, $	Percent of total annual revenue requirements
Direct costs				
Conversion costs				
Operating labor and supervision				
Plant	43,800 man-hr	12.50/man-hr	547,500	11.1
Solids disposal equipment	61,320 man-hr	17.00/man-hr	1,042,400	21.0
Maintenance--plant labor and supervision, 4% of direct investment			173,000	3.5
Landfill operation				
Land preparation			19,400	0.4
Trucks (fuel and maintenance)	1,488,183 tons	0.06/ton	89,300	1.8
Earthmoving equipment (fuel and maintenance)	1,488,183 tons	0.16/ton	238,100	4.8
Electricity	4,308,150 kWh	0.027/kWh	116,300	2.3
Analyses	1,500 hr	17.00/hr	25,500	0.5
Subtotal conversion costs			2,251,500	45.4
Subtotal direct costs			2,251,500	45.4
Indirect costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total capital investment less land and working capital			638,700	12.9
Average cost of capital and taxes at 8.6% of total capital investment			845,000	17.0
Overhead				
Plant, 50% of conversion costs less utilities			1,067,400	21.5
Administrative, 10% of operating labor			159,000	3.2
Subtotal indirect costs			2,710,100	54.6
Total annual revenue requirements			4,961,600	100.0

	$/dry ton	$/wet ton	mills/kWh
Equivalent unit revenue requirements	4.17	3.33	0.47

---

a. Basis
Remaining plant life, 30 yr.
Coal burned, 1,286 klb/hr, 9,000 Btu/kWh, 10,500 Btu/lb.
Power plant on-stream time, 7,000 hr/yr.
Total capital investment, $9,826,000.
Midwest plant location, mid-1980 operating costs.

TABLE A-43. GYPSUM[a]

TOTAL CAPITAL INVESTMENT - PROCESS EQUIPMENT AND INSTALLATION ANALYSIS

(Variation from base case: 500 MW, 25-yr remaining life)

	Total, k$	Percent of direct investment	Percent of total capital investment
Process equipment	1,183	49.3	22.9
Piping and insulation	174	7.3	3.4
Foundation and structural	26	1.1	0.5
Excavation, site preparation, roads and railroads	42	1.7	0.8
Electrical	220	9.2	4.2
Instrumentation	52	2.2	1.0
Buildings	174	7.3	3.4
Subtotal	1,871	78.1	36.2
Services and miscellaneous	28	1.1	0.5
Subtotal excluding trucks and equipment	1,899	79.2	36.7
Trucks and earthmoving equipment	498	20.8	9.7
Subtotal direct investment	2,397	100.0	46.4
Engineering design and supervision	195	8.1	3.8
Architect and engineering contractor	48	2.0	0.9
Construction expense	426	17.8	8.2
Contractor fees	187	7.8	3.6
Subtotal	3,253	135.7	62.9
Contingency	651	27.2	12.6
Subtotal fixed investment	3,904	162.9	75.5
Allowance for startup and modifications	341	14.2	6.6
Interest during construction	468	19.5	9.0
Subtotal capital investment	4,713	196.6	91.1
Land	154	6.4	3.0
Working capital	307	12.8	5.9
Total capital investment	5,174	215.8	100.0

---

[a] Basis
Existing 500-MW plant (25-yr life); 773 klb/hr (15% solids) sludge.
Midwest plant location; average basis for scaling, mid-1979.
Coal analysis (by wt): 3.5% S (dry basis), 16% ash.
Flyash removed with SO_2. Both removed to meet NSPS. Forced-oxidation limestone process with 1.1 stoichiometry based on SO_2 removed. Landfill disposal, 44 acres, 1 mi from scrubber facilities, 80% solids gypsum.

TABLE A-44. GYPSUM[a]

TOTAL ANNUAL REVENUE REQUIREMENTS - REGULATED UTILITY ECONOMICS

(Variation from base case: 500 MW, 25-yr remaining life)

	Annual quantity	Unit cost, $	Total annual revenue requirements, $	Percent of total annual revenue requirements
Direct costs				
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50/man-hr	438,000	13.9
Solids disposal equipment	43,800 man-hr	17.00/man-hr	744,600	23.7
Maintenance--plant labor and supervision, 4% of direct investment			95,900	3.0
Landfill operation				
Land preparation			3,100	0.1
Trucks (fuel and maintenance)	507,077 tons	0.06/ton	30,400	1.0
Earthmoving equipment (fuel and maintenance)	507,077 tons	0.16/ton	81,100	2.6
Electricity	1,712,816 kWh	0.029/kWh	49,700	1.6
Analyses	1,000 hr	17.00/hr	17,000	0.5
Subtotal conversion costs			1,459,800	46.4
Subtotal direct costs			1,459,800	46.4
Indirect costs				
Capital charges				
Depreciation, interim replacement, and insurance at 8.8% of total capital investment less land and working capital			414,700	13.2
Average cost of capital and taxes at 8.6% of total capital investment			445,000	14.2
Overhead				
Plant, 50% of conversion costs less utilities			705,100	22.4
Administrative, 10% of operating labor			118,300	3.8
Subtotal indirect costs			1,683,100	53.6
Total annual revenue requirements			3,142,900	100.0

	$/dry ton	$/wet ton	mills/kWh
Equivalent unit revenue requirements	7.74	6.20	0.89

---

a. Basis

Remaining plant life, 25 yr.
Coal burned, 438 klb/hr, 9,200 Btu/kWh, 10,500 Btu/lb.
Power plant on-stream time, 7,000 hr/yr.
Total capital investment, $5,174,000.
Midwest plant location, mid-1980 operating costs.

TABLE A-45. GYPSUM[a]

TOTAL CAPITAL INVESTMENT - PROCESS EQUIPMENT AND INSTALLATION ANALYSIS

(Variation from base case: 500 MW, 20-yr remaining life)

	Total, k$	Percent of direct investment	Percent of total capital investment
Process equipment	1,183	49.3	23.2
Piping and insulation	174	7.3	3.4
Foundation and structural	26	1.1	0.5
Excavation, site preparation, roads and railroads	42	1.7	0.8
Electrical	220	9.2	4.3
Instrumentation	52	2.2	1.0
Buildings	174	7.2	3.4
Subtotal	1,871	78.0	36.6
Services and miscellaneous	28	1.2	0.5
Subtotal excluding trucks and equipment	1,899	79.2	37.1
Trucks and earthmoving equipment	498	20.8	9.8
Subtotal direct investment	2,397	100.0	46.9
Engineering design and supervision	195	8.1	3.8
Architect and engineering contractor	48	2.0	0.9
Construction expense	426	17.8	8.3
Contractor fees	187	7.8	3.7
Subtotal	3,253	135.7	63.6
Contingency	651	27.2	12.7
Subtotal fixed investment	3,904	162.9	76.3
Allowance for startup and modifications	341	14.2	6.7
Interest during construction	468	19.5	9.1
Subtotal capital investment	4,713	196.6	92.1
Land	95	4.0	1.9
Working capital	307	12.8	6.0
Total capital investment	5,115	213.4	100.0

---

a. Basis
Existing 500-MW plant (20-yr life); 773 klb/hr (15% solids) sludge.
Midwest plant location; average basis for scaling, mid-1979.
Coal analysis (by wt): 3.5% S (dry basis), 16% ash.
Flyash removed with SO_2. Both removed to meet NSPS. Forced-oxidation limestone process with 1.1 stoichiometry, based on SO_2 removed. Landfill disposal, 27 acres, 1 mi from scrubber facilities, 80% solids gypsum.

TABLE A-46. GYPSUM[a]

TOTAL ANNUAL REVENUE REQUIREMENTS - REGULATED UTILITY ECONOMICS

(Variation from base case: 500 MW, 20-yr remaining life)

	Annual quantity	Unit cost, $	Total annual revenue requirements, $	Percent of total annual revenue requirements
Direct costs				
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50/man-hr	438,000	13.9
Solids disposal equipment	43,800 man-hr	17.00/man-hr	744,600	23.5
Maintenance--plant labor and supervision, 4% of direct investment			95,900	3.0
Landfill operation				
Land preparation			2,400	0.1
Trucks (fuel and maintenance)	507,077 tons	0.06/ton	30,400	1.0
Earthmoving equipment (fuel and maintenance)	507,077 tons	0.16/ton	81,100	2.6
Electricity	1,712,816 kWh	0.029/kWh	49,700	1.6
Analyses	1,000 hr	17.00/hr	17,000	0.5
Subtotal conversion costs			1,459,100	46.2
Subtotal direct costs			1,459,100	46.2
Indirect costs				
Capital charges				
Depreciation, interim replacement, and insurance at 9.3% of total capital investment less land and working capital			438,300	13.9
Average cost of capital and taxes at 8.6% of total capital investment			439,900	13.9
Overhead				
Plant, 50% of conversion costs less utilities			704,700	22.3
Administrative, 10% of operating labor			118,300	3.7
Subtotal indirect costs			1,701,200	53.8
Total annual revenue requirements			3,160,300	100.0

	$/dry ton	$/wet ton	mills/kWh
Equivalent unit revenue requirements	7.79	6.24	0.90

---

a. Basis
Remaining plant life, 20 yr.
Coal burned, 438 klb/hr, 9,200 Btu/kWh, 10,500 Btu/lb.
Power plant on-stream time, 7,000 hr/yr.
Total capital investment, $5,115,000.
Midwest plant location, mid-1980 operating costs.

TABLE A-47. GYPSUM[a]

TOTAL CAPITAL INVESTMENT - PROCESS EQUIPMENT AND INSTALLATION ANALYSIS

(Variation from base case: 500 MW, 15-yr remaining life)

	Total, k$	Percent of direct investment	Percent of total capital investment
Process equipment	1,183	49.3	23.5
Piping and insulation	174	7.3	3.4
Foundation and structural	26	1.1	0.5
Excavation, site preparation, roads and railroads	42	1.7	0.8
Electrical	220	9.2	4.3
Instrumentation	52	2.2	1.0
Buildings	174	7.2	3.4
Subtotal	1,871	78.0	36.9
Services and miscellaneous	28	1.2	0.5
Subtotal excluding trucks and equipment	1,899	79.2	37.4
Trucks and earthmoving equipment	498	20.8	9.8
Subtotal direct investment	2,397	100.0	47.2
Engineering design and supervision	195	8.1	3.9
Architect and engineering contractor	48	2.0	0.9
Construction expense	426	17.8	8.4
Contractor fees	187	7.8	3.7
Subtotal	3,253	135.7	64.1
Contingency	651	27.2	12.8
Subtotal fixed investment	3,904	162.9	76.9
Allowance for startup and modifications	341	14.2	6.7
Interest during construction	468	19.5	9.2
Subtotal capital investment	4,713	196.6	92.8
Land	56	2.3	1.1
Working capital	307	12.9	6.1
Total capital investment	5,076	211.8	100.0

---

[a] Basis

Existing 500-MW plant (15-yr life); 773 klb/hr (15% solids) sludge.
Midwest plant location; average basis for scaling, mid-1979.
Coal analysis (by wt): 3.5% S (dry basis), 16% ash.
Flyash removed with SO_2. Both removed to meet NSPS. Forced-oxidation limestone process with 1.1 stoichiometry based on SO_2 removed. Landfill disposal, 16 acres, 1 mi from scrubber facilities, 80% solids gypsum.

TABLE A-48. GYPSUM[a]

TOTAL ANNUAL REVENUE REQUIREMENTS - REGULATED UTILITY ECONOMICS

(Variation from base case: 500 MW, 15-yr remaining life)

	Annual quantity	Unit cost, $	Total annual revenue requirements, $	Percent of total annual revenue requirements
Direct costs				
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50/man-hr	438,000	13.6
Solids disposal equipment	43,800 man-hr	17.00/man-hr	744,600	23.1
Maintenance--plant labor and supervision, 4% of direct investment			95,900	3.0
Landfill operation				
Land preparation			1,900	0.1
Trucks (fuel and maintenance)	507,077 tons	0.06/ton	30,400	0.9
Earthmoving equipment (fuel and maintenance)	507,077 tons	0.16/ton	81,100	2.5
Electricity	1,712,816 kWh	0.029/kWh	49,700	1.5
Analyses	1,000 hr	17.00/hr	17,000	0.5
Subtotal conversion costs			1,458,600	45.2
Subtotal direct costs			1,458,600	45.2
Indirect costs				
Capital charges				
Depreciation, interim replacement, and insurance at 10.8% of total capital investment less land and working capital			509,000	15.8
Average cost of capital and taxes at 8.6% of total capital investment			436,500	13.5
Overhead				
Plant, 50% of conversion costs less utilities			704,500	21.8
Administrative, 10% of operating labor			118,300	3.7
Subtotal indirect costs			1,768,300	54.8
Total annual revenue requirements			3,226,900	100.0

	$/dry ton	$/wet ton	mills/kWh
Equivalent unit revenue requirements	7.96	6.37	0.92

---

a. Basis
Remaining plant life, 15 yr.
Coal burned, 438 klb/hr, 9,200 Btu/kWh, 10,500 Btu/lb.
Power plant on-stream time, 7,000 hr/yr.
Total capital investment, $5,076,000.
Midwest plant location, mid-1980 operating costs.

TABLE A-49. GYPSUM[a]

TOTAL CAPITAL INVESTMENT - PROCESS EQUIPMENT AND INSTALLATION ANALYSIS

(Variation from base case: 2% S)

	Total, k$	Percent of direct investment	Percent of total capital investment
Process equipment	1,031	48.5	21.6
Piping and insulation	140	6.6	2.9
Foundation and structural	21	1.0	0.4
Excavation, site preparation, roads and railroads	42	2.0	0.9
Electrical	205	9.7	4.3
Instrumentation	51	2.4	1.1
Buildings	174	8.2	3.6
Subtotal	1,664	78.4	34.8
Services and miscellaneous	24	1.1	0.5
Subtotal excluding trucks and equipment	1,688	79.5	35.3
Trucks and earthmoving equipment	435	20.5	9.1
Subtotal direct investment	2,123	100.0	44.4
Engineering design and supervision	195	9.1	4.1
Architect and engineering contractor	48	2.3	1.0
Construction expense	386	18.2	8.1
Contractor fees	170	8.0	3.5
Subtotal	2,922	137.6	61.1
Contingency	584	27.5	12.2
Subtotal fixed investment	3,506	165.1	73.3
Allowance for startup and modifications	307	14.5	6.5
Interest during construction	421	19.8	8.8
Subtotal capital investment	4,234	199.4	88.5
Land	284	13.4	5.9
Working capital	264	12.4	5.6
Total capital investment	4,782	225.2	100.0

[a] Basis

New 500-MW plant (30-yr life); 530 klb/hr (15% solids) sludge.
Midwest plant location; average basis for scaling, mid-1979.
Coal analysis (by wt): 2% S (dry basis), 16% ash.
Flyash removed with SO_2. Both removed to meet NSPS. Forced-oxidation limestone process with 1.1 stoichiometry based on SO_2 removed. Landfill disposal, 81 acres, 1 mi from scrubber facilities, 80% solids gypsum.

TABLE A-50. GYPSUM[a]

TOTAL ANNUAL REVENUE REQUIREMENTS - REGULATED UTILITY ECONOMICS

(Variation from base case: 2% S)

	Annual quantity	Unit cost, $	Total annual revenue requirements, $	Percent of total annual revenue requirements
Direct costs				
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50/man-hr	438,000	16.2
Solids disposal equipment	35,040 man-hr	17.00/man-hr	595,700	22.0
Maintenance--plant labor and supervision, 4% of direct investment			84,900	3.1
Landfill operation				
Land preparation			4,600	0.2
Trucks (fuel and maintenance)	347,536 tons	0.06/ton	20,900	0.8
Earthmoving equipment (fuel and maintenance)	347,536 tons	0.16/ton	55,600	2.1
Electricity	1,221,948 kWh	0.029/kWh	35,400	1.3
Analyses	1,000 hr	17.00/hr	17,000	0.6
Subtotal conversion costs			1,252,100	46.3
Subtotal direct costs			1,252,100	46.3
Indirect costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total capital investment less land and working capital			331,500	12.2
Average cost of capital and taxes at 8.6% of total capital investment			411,300	15.2
Overhead				
Plant, 50% of conversion costs less utilities			608,400	22.5
Administrative, 10% of operating labor			103,400	3.8
Subtotal indirect costs			1,454,600	53.7
Total annual revenue requirements			2,706,700	100.0

	$/dry ton	$/wet ton	mills/kWh
Equivalent unit revenue requirements	9.74	7.79	0.77

---

a. Basis
Remaining plant life, 30 yr.
Coal burned, 421 klb/hr, 9,000 Btu/kWh, 10,700 Btu/lb.
Power plant on-stream time, 7,000 hr/yr.
Total capital investment, $4,782,000.
Midwest plant location, mid-1980 operating costs.

TABLE A-51. GYPSUM[a]

TOTAL CAPITAL INVESTMENT - PROCESS EQUIPMENT AND INSTALLATION ANALYSIS

(Variation from base case: 5% S)

	Total, k$	Percent of direct investment	Percent of total capital investment
Process equipment	1,290	49.6	21.9
Piping and insulation	181	7.0	3.0
Foundation and structural	27	1.0	0.5
Excavation, site preparation, roads and railroads	47	1.8	0.8
Electrical	227	8.7	3.9
Instrumentation	52	2.0	0.9
Buildings	174	6.7	3.0
Subtotal	1,998	76.8	34.0
Services and miscellaneous	29	1.1	0.5
Subtotal excluding trucks and equipment	2,027	77.9	34.5
Trucks and earthmoving equipment	575	22.1	9.7
Subtotal direct investment	2,602	100.0	44.2
Engineering design and supervision	195	7.5	3.3
Architect and engineering contractor	48	1.8	0.8
Construction expense	449	17.3	7.6
Contractor fees	199	7.6	3.5
Subtotal	3,493	134.2	59.4
Contingency	699	26.9	11.8
Subtotal fixed investment	4,192	161.1	71.2
Allowance for startup and modifications	362	13.9	6.2
Interest during construction	503	19.3	8.5
Subtotal capital investment	5,057	194.3	85.9
Land	511	19.7	8.7
Working capital	316	12.1	5.4
Total capital investment	5,884	226.1	100.0

a. Basis
New 500-MW plant (30-yr life); 960 klb/hr (15% solids) sludge.
Midwest plant location; average basis for scaling, mid-1979.
Coal analysis (by wt): 5% S (dry basis), 16% ash.
Flyash removed with SO_2. Both removed to meet NSPS. Forced-oxidation limestone process with 1.1 stoichiometry based on SO_2 removed. Landfill disposal, 146 acres, 1 mi from scrubber facilities, 80% solids gypsum.

TABLE A-52. GYPSUM[a]

TOTAL ANNUAL REVENUE REQUIREMENTS - REGULATED UTILITY ECONOMICS

(Variation from base case: 5% S)

	Annual quantity	Unit cost, $	Total annual revenue requirements, $	Percent of total annual revenue requirements
Direct costs				
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50/man-hr	438,000	13.5
Solids disposal equipment	43,800 man-hr	17.00/man-hr	744,600	22.9
Maintenance--plant labor and supervision, 4% of direct investment			104,100	3.2
Landfill operation				
Land preparation			8,300	0.3
Trucks (fuel and maintenance)	629,808 tons	0.06/ton	37,800	1.1
Earthmoving equipment (fuel and maintenance)	629,808 tons	0.16/ton	100,800	3.1
Electricity	1,906,030 kWh	0.029/kWh	55,300	1.7
Analyses	1,000 hr	17.00/hr	17,000	0.5
Subtotal conversion costs			1,505,900	46.3
Subtotal direct costs			1,505,900	46.3
Indirect costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total capital investment less land and working capital			396,000	12.2
Average cost of capital and taxes at 8.6% of total capital investment			506,000	15.6
Overhead				
Plant, 50% of conversion costs less utilities			725,300	22.3
Administrative, 10% of operating labor			118,300	3.6
Subtotal indirect costs			1,745,600	53.7
Total annual revenue requirements			3,251,500	100.0

	$/dry ton	$/wet ton	mills/kWh
Equivalent unit revenue requirements	6.45	5.16	0.93

---

a. Basis

Remaining plant life, 30 yr.
Coal burned, 433 klb/hr, 9,000 Btu/kWh, 10,400 Btu/lb.
Power plant on-stream time, 7,000 hr/yr.
Total capital investment, $5,884,000.
Midwest plant location, mid-1980 operating costs.

TABLE A-53. GYPSUM[a]

TOTAL CAPITAL INVESTMENT - PROCESS EQUIPMENT AND INSTALLATION ANALYSIS

(Variation from base case: 12% ash)

	Total, k$	Percent of direct investment	Percent of total capital investment
Process equipment	1,109	50.0	22.0
Piping and insulation	148	6.7	3.0
Foundation and structural	21	0.9	0.4
Excavation, site preparation, roads and railroads	41	1.9	0.8
Electrical	212	9.6	4.2
Instrumentation	52	2.3	1.0
Buildings	174	7.8	3.5
Subtotal	1,757	79.2	34.9
Services and miscellaneous	26	1.2	0.5
Subtotal excluding trucks and equipment	1,783	80.4	35.4
Trucks and earthmoving equipment	435	19.6	8.6
Subtotal direct investment	2,218	100.0	44.0
Engineering design and supervision	196	8.9	3.9
Architect and engineering contractor	49	2.2	1.0
Construction expense	404	18.2	8.0
Contractor fees	176	7.9	3.5
Subtotal	3,043	137.2	60.4
Contingency	609	27.5	12.0
Subtotal fixed investment	3,652	164.7	72.4
Allowance for startup and modifications	322	14.5	6.4
Interest during construction	438	19.7	8.7
Subtotal capital investment	4,412	198.9	87.5
Land	329	14.8	6.5
Working capital	301	13.6	6.0
Total capital investment	5,042	227.3	100.0

a. Basis

New 500-MW plant (30-yr life); 623 klb/hr (15% solids) sludge.
Midwest plant location; average basis for scaling, mid-1979.
Coal analysis (by wt): 3.5% S (dry basis), 12% ash.
Flyash removed with SO_2. Both removed to meet NSPS. Forced-oxidation limestone process with 1.1 stoichiometry based on SO_2 removed. Landfill disposal, 94 acres, 1 mi from scrubber facilities, 80% solids gypsum.

TABLE A-54. GYPSUM[a]

TOTAL ANNUAL REVENUE REQUIREMENTS - REGULATED UTILITY ECONOMICS

(Variation from base case: 12% ash)

	Annual quantity	Unit cost, $	Total annual revenue requirements, $	Percent of total annual revenue requirements
Direct costs				
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50/man-hr	438,000	14.5
Solids disposal equipment	43,800 man-hr	17.00/man-hr	744,600	24.7
Maintenance--plant labor and supervision, 4% of direct investment			88,700	2.9
Landfill operation				
Land preparation			5,400	0.2
Trucks (fuel and maintenance)	408,653 tons	0.06/ton	24,500	0.8
Earthmoving equipment (fuel and maintenance)	408,653 tons	0.16/ton	65,400	2.2
Electricity	1,566,600 kWh	0.029/kWh	45,400	1.5
Analyses	1,000 hr	17.00/hr	17,000	0.5
Subtotal conversion costs			1,429,000	47.3
Subtotal direct costs			1,429,000	47.3
Indirect costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total capital investment less land and working capital			345,500	11.5
Average cost of capital and taxes at 8.6% of total capital investment			433,600	14.4
Overhead				
Plant, 50% of conversion costs less utilities			691,800	22.9
Administrative, 10% of operating labor			118,300	3.9
Subtotal indirect costs			1,589,200	52.7
Total annual revenue requirements			3,018,200	100.0

	$/dry ton	$/wet ton	mills/kWh
Equivalent unit revenue requirements	9.23	7.39	0.86

---

a. Basis
Remaining plant life, 30 yr.
Coal burned, 405 klb/hr, 9,000 Btu/kWh, 11,100 Btu/lb.
Power plant on-stream time, 7,000 hr/yr.
Total capital investment, $5,042,000.
Midwest plant location, mid-1980 operating costs.

TABLE A-55. GYPSUM[a]

TOTAL CAPITAL INVESTMENT - PROCESS EQUIPMENT AND INSTALLATION ANALYSIS

(Variation from base case: 20% ash)

	Total, k$	Percent of direct investment	Percent of total capital investment
Process equipment	1,271	50.7	22.3
Piping and insulation	182	7.3	3.2
Foundation and structural	26	1.0	0.4
Excavation, site preparation, roads and railroads	46	1.8	0.8
Electrical	227	9.1	4.0
Instrumentation	52	2.1	0.9
Buildings	174	6.9	3.1
Subtotal	1,978	78.9	34.7
Services and miscellaneous	30	1.2	0.5
Subtotal excluding trucks and equipment	2,008	80.1	35.2
Trucks and earthmoving equipment	498	19.9	8.7
Subtotal direct investment	2,506	100.0	43.9
Engineering design and supervision	196	7.8	3.4
Architect and engineering contractor	49	2.0	0.9
Construction expense	446	17.8	7.8
Contractor fees	193	7.7	3.4
Subtotal	3,390	135.3	59.4
Contingency	678	27.0	11.9
Subtotal fixed investment	4,068	162.3	71.3
Allowance for startup and modifications	357	14.3	6.3
Interest during construction	488	19.5	8.5
Subtotal capital investment	4,913	196.1	86.1
Land	480	19.1	8.4
Working capital	314	12.5	5.5
Total capital investment	5,707	227.7	100.0

a. Basis
New 500-MW plant (30-yr life); 905 klb/hr (15% solids) sludge.
Midwest plant location; average basis for scaling, mid-1979.
Coal analysis (by wt): 3.5% S (dry basis), 20% ash.
Flyash removed with SO_2. Both removed to meet NSPS. Forced-oxidation limestone process with 1.1 stoichiometry based on SO_2 removed. Landfill disposal, 137 acres, 1 mi from scrubber facilities, 80% solids gypsum.

TABLE A-56. GYPSUM[a]

TOTAL ANNUAL REVENUE REQUIREMENTS - REGULATED UTILITY ECONOMICS

(Variation from base case: 20% ash)

	Annual quantity	Unit cost, $	Total annual revenue requirements, $	Percent of total annual revenue requirements
Direct costs				
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50/man-hr	438,000	13.7
Solids disposal equipment	43,800 man-hr	17.00/man-hr	744,600	23.2
Maintenance--plant labor and supervision, 4% of direct investment			100,200	3.1
Landfill operation				
Land preparation			7,800	0.2
Trucks (fuel and maintenance)	594,003 tons	0.06/ton	35,600	1.1
Earthmoving equipment (fuel and maintenance)	594,003 tons	0.16/ton	95,000	3.0
Electricity	1,906,030 kWh	0.029/kWh	55,300	1.7
Analyses	1,000 hr	17.00/hr	17,000	0.6
Subtotal conversion costs			1,493,500	46.6
Subtotal direct costs			1,493,500	46.6
Indirect costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total capital investment less land and working capital			384,700	12.0
Average cost of capital and taxes at 8.6% of total capital investment			490,800	15.3
Overhead				
Plant, 50% of conversion costs less utilities			719,100	22.4
Administrative, 10% of operating labor			118,300	3.7
Subtotal indirect costs			1,712,900	53.4
Total annual revenue requirements			3,206,400	100.0

	$/dry ton	$/wet ton	mills/kWh
Equivalent unit revenue requirements	6.75	5.40	0.92

---

a. Basis
Remaining plant life, 30 yr.
Coal burned, 455 klb/hr, 9,000 Btu/kWh, 9,900 Btu/lb.
Power plant on-stream time, 7,000 hr/yr.
Total capital investment, $5,707,000.
Midwest plant location, mid-1980 operating costs.

TABLE A-57. GYPSUM[a]

TOTAL CAPITAL INVESTMENT - PROCESS EQUIPMENT AND INSTALLATION ANALYSIS

(Variation from base case: 1.0 lime stoichiometry)

	Total, k$	Percent of direct investment	Percent of total capital investment
Process equipment	1,167	50.0	22.0
Piping and insulation	173	7.4	3.2
Foundation and structural	24	1.0	0.4
Excavation, site preparation, roads and railroads	42	1.8	0.8
Electrical	220	9.4	4.1
Instrumentation	52	2.2	1.0
Buildings	174	7.5	3.3
Subtotal	1,852	79.3	34.8
Services and miscellaneous	28	1.2	0.6
Subtotal excluding trucks and equipment	1,880	80.5	35.4
Trucks and earthmoving equipment	455	19.5	8.5
Subtotal direct investment	2,335	100.0	43.9
Engineering design and supervision	196	8.4	3.7
Architect and engineering contractor	49	2.1	0.9
Construction expense	422	18.1	7.9
Contractor fees	183	7.8	3.4
Subtotal	3,185	136.4	59.9
Contingency	637	27.3	12.0
Subtotal fixed investment	3,822	163.7	71.9
Allowance for startup and modifications	337	14.4	6.3
Interest during construction	459	19.7	8.7
Subtotal capital investment	4,618	197.8	86.9
Land	389	16.7	7.3
Working capital	308	13.1	5.8
Total capital investment	5,315	227.6	100.0

---

a. Basis

New 500-MW plant (30-yr life); 729 klb/hr (10% solids) sludge.
Midwest plant location; average basis for scaling, mid-1979.
Coal analysis (by wt): 3.5% S (dry basis), 16% ash.
Flyash removed with SO_2. Both removed to meet NSPS. Forced-oxidation limestone process with 1.0 stoichiometry based on SO_2 removed. Landfill disposal, 111 acres, 1 mi from scrubber facilities, 80% solids gypsum.

TABLE A-58. GYPSUM[a]

TOTAL ANNUAL REVENUE REQUIREMENTS - REGULATED UTILITY ECONOMICS

(Variation from base case: 1.0 lime stoichiometry)

	Annual quantity	Unit cost, $	Total annual revenue requirements, $	Percent of total annual revenue requirements
Direct costs				
Conversion costs				
Operating labor and supervision				
Plant				
Solids disposal equipment	35,040 man-hr	12.50/man-hr	438,000	14.1
Maintenance--plant labor and supervision, 4% of direct investment	43,800 man-hr	17.00/man-hr	744,600	24.0
Landfill operation			100,200	3.2
Land preparation				
Trucks (fuel and maintenance)			6,300	0.2
Earthmoving equipment (fuel and maintenance)	478,198 tons	0.06/ton	28,700	0.9
Electricity	478,198 tons	0.16/ton	76,500	2.5
Analyses	1,712,816 kWh	0.029/kWh	49,700	1.6
Subtotal conversion costs	1,000 hr	17.00/hr	17,000	0.6
			1,461,000	47.1
Subtotal direct costs				
			1,461,000	47.1
Indirect costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total capital investment less land and working capital				
Average cost of capital and taxes at 8.6% of total capital investment			361,600	11.7
Overhead			457,100	14.7
Plant, 50% of conversion costs less utilities				
Administrative, 10% of operating labor			705,700	22.7
Subtotal indirect costs			118,300	3.8
			1,642,700	52.9
Total annual revenue requirements				
			3,103,700	100.0

	$/dry ton	$/wet ton	mills/kWh
Equivalent unit revenue requirements	8.11	6.49	0.89

---

a. Basis

Remaining plant life, 30 yr.
Coal burned, 429 klb/hr, 9,000 Btu/kWh, 10,500 Btu/lb.
Power plant on-stream time, 7,000 hr/yr.
Total capital investment, $5,315,000.
Midwest plant location, mid-1980 operating costs.

TABLE A-59. GYPSUM[a]

TOTAL CAPITAL INVESTMENT - PROCESS EQUIPMENT AND INSTALLATION ANALYSIS

(Variation from base case: 5 mi to disposal)

	Total, k$	Percent of direct investment	Percent of total capital investment
Process equipment	1,179	45.8	20.6
Piping and insulation	174	6.7	3.0
Foundation and structural	25	1.0	0.4
Excavation, site preparation, roads and railroads	42	1.6	0.7
Electrical	191	7.4	3.3
Instrumentation	52	2.0	0.9
Buildings	174	6.8	3.0
Subtotal	1,837	71.3	31.9
Services and miscellaneous	27	1.1	0.5
Subtotal excluding trucks and equipment	1,864	72.4	32.4
Trucks and earthmoving equipment	712	27.6	12.4
Subtotal direct investment	2,576	100.0	44.8
Engineering design and supervision	196	7.6	3.4
Architect and engineering contractor	49	1.9	0.9
Construction expense	419	16.3	7.3
Contractor fees	197	7.6	3.4
Subtotal	3,437	133.4	59.8
Contingency	687	26.7	11.9
Subtotal fixed investment	4,124	160.1	71.7
Allowance for startup and modifications	341	13.3	5.9
Interest during construction	495	19.2	8.7
Subtotal capital investment	4,960	192.6	86.3
Land	403	15.6	7.0
Working capital	387	15.0	6.7
Total capital investment	5,750	223.2	100.0

[a] Basis
New 500-MW plant (30-yr life); 756 klb/hr (15% solids) sludge.
Midwest plant location; average basis for scaling, mid-1979.
Coal analysis (by wt): 3.5% S (dry basis), 16% ash.
Flyash removed with SO_2. Both removed to meet NSPS. Forced-oxidation limestone process with 1.1 stoichiometry based on SO_2 removed. Landfill disposal, 115 acres, 5 mi from scrubber facilities, 80% solids gypsum.

TABLE A-60. GYPSUM[a]

TOTAL ANNUAL REVENUE REQUIREMENTS - REGULATED UTILITY ECONOMICS

(Variation from base case: 5 mi to disposal)

	Annual quantity	Unit cost, $	Total annual revenue requirements, $	Percent of total annual revenue requirements
Direct costs				
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50/man-hr	438,000	11.9
Solids disposal equipment	61,320 man-hr	17.00/man-hr	1,042,400	28.2
Maintenance--plant labor and supervision, 4% of direct investment			103,000	2.8
Landfill operation				
Land preparation			6,600	0.2
Trucks (fuel and maintenance)	496,048 tons	0.20/ton	99,200	2.7
Earthmoving equipment (fuel and maintenance)	496,048 tons	0.16/ton	79,400	2.1
Electricity	1,699,761 kWh	0.029/kWh	49,300	1.3
Analyses	1,000 hr	17.00/hr	17,000	0.5
Subtotal conversion costs			1,834,900	49.7
Subtotal direct costs			1,834,900	49.7
Indirect costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total capital investment less land and working capital			361,600	9.7
Average cost of capital and taxes at 8.6% of total capital investment			457,100	12.4
Overhead				
Plant, 50% of conversion costs less utilities			892,800	24.2
Administrative, 10% of operating labor			148,000	4.0
Subtotal indirect costs			1,859,500	50.3
Total annual revenue requirements			3,694,400	100.0

	$/dry ton	$/wet ton	mills/kWh
Equivalent unit revenue requirements	9.31	7.45	1.05

---

a. Basis

Remaining plant life, 30 yr.
Coal burned, 429 klb/hr, 9,000 Btu/kWh, 10,500 Btu/lb.
Power plant on-stream time, 7,000 hr/yr.
Total capital investment, $5,750,000.
Midwest plant location, mid-1980 operating costs.

TABLE A-61. GYPSUM[a]

TOTAL CAPITAL INVESTMENT - PROCESS EQUIPMENT AND INSTALLATION ANALYSIS

(Variation from base case: 10 mi to disposal)

	Total, k$	Percent of direct investment	Percent of total capital investment
Process equipment	1,179	43.4	19.6
Piping and insulation	174	6.4	2.9
Foundation and structural	25	0.9	0.4
Excavation, site preparation, roads and railroads	42	1.6	0.7
Electrical	191	7.0	3.2
Instrumentation	52	1.9	0.9
Buildings	174	6.4	2.9
Subtotal	1,837	67.7	30.6
Services and miscellaneous	28	1.0	0.5
Subtotal excluding trucks and equipment	1,865	68.7	31.1
Trucks and earthmoving equipment	849	31.3	14.1
Subtotal direct investment	2,714	100.0	45.2
Engineering design and supervision	196	7.2	3.3
Architect and engineering contractor	49	1.8	0.8
Construction expense	419	15.4	7.0
Contractor fees	205	7.6	3.4
Subtotal	3,583	132.0	59.7
Contingency	716	26.4	11.9
Subtotal fixed investment	4,299	158.4	71.6
Allowance for startup and modifications	345	12.7	5.7
Interest during construction	516	19.0	8.6
Subtotal capital investment	5,160	190.1	85.9
Land	403	14.9	6.7
Working capital	442	16.3	7.4
Total capital investment	6,005	221.3	100.0

[a] Basis
New 500-MW plant (30-yr life); 756 klb/hr (15% solids) sludge.
Midwest plant location; average basis for scaling, mid-1979.
Coal analysis (by wt): 3.5% S (dry basis), 16% ash.
Flyash removed with SO_2. Both removed to meet NSPS. Forced-oxidation limestone process with 1.1 stoichiometry based on SO_2 removed. Landfill disposal, 115 acres, 10 mi from scrubber facilities, 80% solids gypsum.

TABLE A-32. GYPSUM[a]

TOTAL ANNUAL REVENUE REQUIREMENTS - REGULATED UTILITY ECONOMICS

(Variation from base case: 10 mi to disposal)

	Annual quantity	Unit cost, $	Total annual revenue requirements, $	Percent of total annual revenue requirements
Direct costs				
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50/man-hr	438,000	10.2
Solids disposal equipment	70,080 man-hr	17.00/man-hr	1,192,400	27.8
Maintenance--plant labor and supervision, 4% of direct investment			119,700	2.8
Landfill operation				
Land preparation			6,600	0.2
Trucks (fuel and maintenance)	496,048 tons	0.39/ton	193,500	4.5
Earthmoving equipment (fuel and maintenance)	496,048 tons	0.16/ton	79,400	1.8
Electricity	1,699,761 kWh	0.029/kWh	49,300	1.2
Analyses	1,000 hr	17.00/hr	17,000	0.4
Subtotal conversion costs			2,095,900	48.9
Subtotal direct costs			2,095,900	48.9
Indirect costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total capital investment less land and working capital			443,900	10.3
Average cost of capital and taxes at 8.6% of total capital investment			560,200	13.1
Overhead				
Plant, 50% of conversion costs less utilities			1,023,300	23.9
Administrative, 10% of operating labor			163,000	3.8
Subtotal indirect costs			2,190,400	51.1
Total annual revenue requirements			4,286,300	100.0

	$/dry ton	$/wet ton	mills/kWh
Equivalent unit revenue requirements	10.80	8.64	1.22

---

a. Basis
Remaining plant life, 30 yr.
Coal burned, 429 klb/hr, 9,000 Btu/kWh, 10,500 Btu/lb.
Power plant on-stream time, 7,000 hr/yr.
Total capital investment, $6,005,000.
Midwest plant location, mid-1980 operating costs.

TABLE A-63. GYPSUM[a]

TOTAL CAPITAL INVESTMENT - PROCESS EQUIPMENT AND INSTALLATION ANALYSIS

(Variation from base case: 500 MW, 7,000-hr/yr operation)

	Total, k$	Percent of direct investment	Percent of total capital investment
Process equipment	1,179	49.3	20.8
Piping and insulation	174	7.3	3.1
Foundation and structural	25	0.9	0.4
Excavation, site preparation, roads and railroads	42	1.8	0.7
Electrical	220	9.2	3.9
Instrumentation	52	2.2	0.9
Buildings	174	7.3	3.1
Subtotal	1,866	78.0	32.9
Services and miscellaneous	28	1.2	0.5
Subtotal excluding trucks and equipment	1,894	79.2	33.4
Trucks and earthmoving equipment	498	20.8	8.8
Subtotal direct investment	2,392	100.0	42.2
Engineering design and supervision	196	8.2	3.5
Architect and engineering contractor	49	2.0	0.8
Construction expense	425	17.8	7.5
Contractor fees	186	7.8	3.3
Subtotal	3,248	135.8	57.3
Contingency	650	27.2	11.5
Subtotal fixed investment	3,898	163.0	68.7
Allowance for startup and modifications	340	14.2	6.0
Interest during construction	468	19.5	8.3
Subtotal capital investment	4,706	196.7	83.0
Land	658	27.5	11.6
Working capital	308	12.9	5.4
Total capital investment	5,672	237.1	100.0

[a] Basis

New 500-MW plant (30-yr life); 756 klb/hr (15% solids) sludge.
Midwest plant location; average basis for scaling, mid-1979.
Coal analysis (by wt): 3.5% S (dry basis), 16% ash.
Flyash removed with SO_2. Both removed to meet NSPS. Forced-oxidation limestone process with 1.1 stoichiometry based on SO_2 removed. Landfill disposal, 188 acres, 1 mi from scrubber facilities, 80% solids gypsum.

TABLE A-64. GYPSUM[a]

TOTAL ANNUAL REVENUE REQUIREMENTS - REGULATED UTILITY ECONOMICS

(Variation from base case: 500 MW, 7,000-hr/yr operating profile)

	Annual quantity	Unit cost, $	Total annual revenue requirements, $	Percent of total annual revenue requirements
Direct costs				
Conversion costs				
Operating labor and supervision				
Plant	35,040 man-hr	12.50/man-hr	438,000	13.9
Solids disposal equipment	43,800 man-hr	17.00/man-hr	744,600	23.7
Maintenance--plant labor and supervision, 4% of direct investment			95,700	3.0
Landfill operation				
Land preparation			10,700	0.3
Trucks (fuel and maintenance)	496,048 tons	0.06/ton	29,800	1.0
Earthmoving equipment (fuel and maintenance)	496,048 tons	0.16/ton	79,400	2.5
Electricity	1,699,761 kWh	0.029/kWh	49,300	1.6
Analyses	1,000 hr	17.00/hr	17,000	0.5
Subtotal conversion costs			1,464,500	46.5
Subtotal direct costs			1,464,500	46.5
Indirect costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total capital investment less land and working capital			368,500	11.7
Average cost of capital and taxes at 8.6% of total capital investment			487,400	15.5
Overhead				
Plant, 50% of conversion costs less utilities			707,600	22.5
Administrative, 10% of operating labor			118,300	3.8
Subtotal indirect costs			1,681,800	53.5
Total annual revenue requirements			3,146,300	100.0

	$/dry ton	$/wet ton	mills/kWh
Equivalent unit revenue requirements	7.93	6.34	0.90

---

a. Basis

Remaining plant life, 30 yr.
Coal burned, 429 klb/hr, 9,000 Btu/kWh, 10,500 Btu/lb.
Power plant on-stream time, 7,000 hr/yr.
Total capital investment, $5,672,000.
Midwest plant location, mid-1980 operating costs.

TABLE A-65. GYPSUM[a]

TOTAL CAPITAL INVESTMENT - PROCESS EQUIPMENT AND INSTALLATION ANALYSIS

(Variation from base case: 200 MW, 7,000-hr/yr constant onstream)

	Total, k$	Percent of direct investment	Percent of total capital investment
Process equipment	794	44.8	19.4
Piping and insulation	124	7.0	3.0
Foundation and structural	17	1.0	0.4
Excavation, site preparation, roads and railroads	38	2.0	0.9
Electrical	180	10.2	4.4
Instrumentation	44	2.5	1.1
Buildings	174	9.8	4.3
Subtotal	1,371	77.4	33.5
Services and miscellaneous	20	1.1	0.5
Subtotal excluding trucks and equipment	1,391	78.5	34.0
Trucks and earthmoving equipment	381	21.5	9.3
Subtotal direct investment	1,772	100.0	43.3
Engineering design and supervision	172	9.7	4.2
Architect and engineering contractor	43	2.4	1.1
Construction expense	329	18.6	8.0
Contractor fees	148	8.3	3.6
Subtotal	2,464	139.0	60.2
Contingency	493	27.8	12.0
Subtotal fixed investment	2,957	166.9	72.2
Allowance for startup and modifications	258	14.6	6.3
Interest during construction	355	20.0	8.7
Subtotal capital investment	3,570	201.5	87.2
Land	270	15.2	6.6
Working capital	253	14.3	6.2
Total capital investment	4,093	231.0	100.0

[a] Basis

New 200-MW plant (30-yr life); 309 klb/hr (15% solids) sludge.
Midwest plant location; average basis for scaling, mid-1979.
Coal analysis (by wt): 3.5% S (dry basis), 16% ash.
Flyash removed with SO_2. Both removed to meet NSPS. Forced-oxidation limestone process with 1.1 stoichiometry based on SO_2 removed. Landfill disposal, 77 acres, 1 mi from scrubber facilities, 80% solids gypsum.

TABLE A-66. GYPSUM[a]

TOTAL ANNUAL REVENUE REQUIREMENTS - REGULATED UTILITY ECONOMICS

(Variation from base case: 200 MW, 7,000-hr/yr constant onstream)

	Annual quantity	Unit cost, $	Total annual revenue requirements, $	Percent of total annual revenue requirements
Direct costs				
Conversion costs				
Operating labor and supervision				
Plant	26,280 man-hr	12.50/man-hr	328,500	13.7
Solids disposal equipment	35,040 man-hr	17.00/man-hr	595,700	24.8
Maintenance--plant labor and supervision, 4% of direct investment			70,900	3.0
Landfill operation				
Land preparation			2,700	0.1
Trucks (fuel and maintenance)	202,836 tons	0.06/ton	12,200	0.5
Earthmoving equipment (fuel and maintenance)	202,836 tons	0.16/ton	32,500	1.4
Electricity	725,858 kWh	0.031/kWh	22,500	0.9
Analyses	1,000 hr	17.00/hr	17,000	0.7
Subtotal conversion costs			1,082,000	45.1
Subtotal direct costs			1,082,000	45.1
Indirect costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total capital investment less land and working capital			279,500	11.6
Average cost of capital and taxes at 8.6% of total capital investment			352,000	14.7
Overhead				
Plant, 50% of conversion costs less utilities			584,500	24.3
Administrative, 10% of operating labor			103,400	4.3
Subtotal indirect costs			1,319,400	54.9
Total annual revenue requirements			2,401,400	100.0

	$/dry ton	$/wet ton	mills/kWh
Equivalent unit revenue requirements	14.75	11.79	1.72

---

a. Basis
Remaining plant life, 30 yr.
Coal burned, 175 klb/hr, 9,000 Btu/kWh, 10,500 Btu/lb.
Power plant on-stream time, 7,000 hr/yr.
Total capital investment, $4,093,000.
Midwest plant location, mid-1980 operating costs.

TABLE A-67. GYPSUM[a]

TOTAL CAPITAL INVESTMENT - PROCESS EQUIPMENT AND INSTALLATION ANALYSIS

(Variation from base case: 1,500 MW, 7,000-hr/yr constant onstream)

	Total, k$	Percent of direct investment	Percent of total capital investment
Process equipment	2,215	51.2	20.9
Piping and insulation	290	6.7	2.7
Foundation and structural	47	1.1	0.4
Excavation, site preparation, roads and railroads	59	1.4	0.6
Electrical	374	8.6	3.5
Instrumentation	55	1.3	0.5
Buildings	294	6.8	2.8
Subtotal	3,334	77.1	31.4
Services and miscellaneous	50	1.1	0.5
Subtotal excluding trucks and equipment	3,384	78.2	31.9
Trucks and earthmoving equipment	942	21.8	8.9
Subtotal direct investment	4,326	100.0	40.8
Engineering design and supervision	264	6.1	2.5
Architect and engineering contractor	66	1.5	0.6
Construction expense	688	15.9	6.5
Contractor fees	292	6.8	2.8
Subtotal	5,636	130.3	53.2
Contingency	1,127	26.0	10.6
Subtotal fixed investment	6,763	156.3	63.8
Allowance for startup and modifications	582	13.5	5.5
Interest during construction	812	18.8	7.7
Subtotal capital investment	8,157	188.6	77.0
Land	1,978	45.7	18.6
Working capital	468	10.8	4.4
Total capital investment	10,603	245.1	100.0

a. Basis

New 1500-MW plant (30-yr life); 2,268 klb/hr (15% solids) sludge.
Midwest plant location; average basis for scaling, mid-1979.
Coal analysis (by wt): 3.5% S (dry basis), 16% ash.
Flyash removed with SO_2. Both removed to meet NSPS. Forced-oxidation limestone process with 1.1 stoichiometry based on SO_2 removed. Landfill disposal, 565 acres, 1 mi from scrubber facilities, 80% solids gypsum.

TABLE A-53. GYPSUM[a]

TOTAL ANNUAL REVENUE REQUIREMENTS - REGULATED UTILITY ECONOMICS

(Variation from base case: 1,500 MW, 7,000-hr/yr constant onstream)

	Annual quantity	Unit cost, $	Total annual revenue requirements, $	Percent of total annual revenue requirements
Direct costs				
Conversion costs				
Operating labor and supervision				
Plant	43,800 man-hr	12.50/man-hr	547,500	10.9
Solids disposal equipment	61,320 man-hr	17.00/man-hr	1,042,400	20.7
Maintenance--plant labor and supervision, 4% of direct investment			173,000	3.4
Landfill operation				
Land preparation			19,400	0.4
Trucks (fuel and maintenance)	1,488,183 tons	0.06/ton	89,300	1.8
Earthmoving equipment (fuel and maintenance)	1,488,183 tons	0.16/ton	238,100	4.7
Electricity	4,308,150 kWh	0.029/kWh	116,300	2.3
Analyses	1,500 hr	17.00/hr	25,000	0.5
Subtotal conversion costs			2,251,000	44.8
Subtotal direct costs			2,251,000	44.8
Indirect costs				
Capital charges				
Depreciation, interim replacement, and insurance at 7.83% of total capital investment less land and working capital			638,700	12.7
Average cost of capital and taxes at 8.6% of total capital investment			911,900	18.1
Overhead				
Plant, 50% of conversion costs less utilities			1,067,400	21.2
Administrative, 10% of operating labor			159,000	3.2
Subtotal indirect costs			2,777,000	55.2
Total annual revenue requirements			5,028,000	100.0

	$/dry ton	$/wet ton	mills/kWh
Equivalent unit revenue requirements	4.23	3.37	0.48

---

a. Basis
Remaining plant life, 30 yr.
Coal burned, 1,286 klb/hr, 9,000 Btu/kWh, 10,500 Btu/lb.
Power plant on-stream time, 7,000 hr/yr.
Total capital investment, $10,603,000.
Midwest plant location, mid-1980 operating costs.

APPENDIX B

DECLINING OPERATING PROFILE - LIFETIME REVENUE REQUIREMENTS

Preceding page blank

TABLE B-1

LIME/LIMESTONE SLUDGE DISPOSAL - SLUDGE BLENDING PROCESS 200 MW NEW UNIT, 3.5% S IN FUEL, 16% ASH IN COAL, REGULATED CO. ECONOMICS

FIXED INVESTMENT: $ 6126000

YEARS AFTER POWER UNIT START	ANNUAL OPERATION, KW-HR/KW	POWER UNIT HEAT REQUIREMENT, MILLION BTU /YEAR	POWER UNIT FUEL CONSUMPTION, TONS COAL /YEAR	SULFUR REMOVED BY POLLUTION CONTROL PROCESS, TONS/YEAR	BY-PRODUCT RATE, EQUIVALENT TONS/YEAR WASTE SOLIDS	NET REVENUE, $/TON WASTE SOLIDS	TOTAL OP. COST INCLUDING REGULATED ROI FOR POWER COMPANY, $/YEAR	TOTAL NET SALES REVENUE, $/YEAR	NET ANNUAL INCREASE (DECREASE) IN COST OF POWER, $	CUMULATIVE NET INCREASE (DECREASE) IN COST OF POWER, $
1	7000	12880000	613300	14600	224400	0.0	3289200	0	3289200	3289200
2	7000	12880000	613300	14600	224400	0.0	3256700	0	3256700	6545900
3	7000	12880000	613300	14600	224400	0.0	3224200	0	3224200	9770100
4	7000	12880000	613300	14600	224400	0.0	3191700	0	3191700	12961800
5	7000	12880000	613300	14600	224400	0.0	3159200	0	3159200	16121000
6	7000	12880000	613300	14600	224400	0.0	3126700	0	3126700	19247700
7	7000	12880000	613300	14600	224400	0.0	3094200	0	3094200	22341900
8	7000	12880000	613300	14600	224400	0.0	3061700	0	3061700	25403600
9	7000	12880000	613300	14600	224400	0.0	3029200	0	3029200	28432800
10	7000	12880000	613300	14600	224400	0.0	2996800	0	2996800	31429600
11	5000	9200000	438100	10400	160300	0.0	2668100	0	2668100	34097700
12	5000	9200000	438100	10400	160300	0.0	2635600	0	2635600	36733300
13	5000	9200000	438100	10400	160300	0.0	2603100	0	2603100	39336400
14	5000	9200000	438100	10400	160300	0.0	2570600	0	2570600	41907000
15	5000	9200000	438100	10400	160300	0.0	2538100	0	2538100	44445100
16	3500	6440000	306700	7300	112200	0.0	2248000	0	2248000	46693100
17	3500	6440000	306700	7300	112200	0.0	2215500	0	2215500	48908600
18	3500	6440000	306700	7300	112200	0.0	2183000	0	2183000	51091600
19	3500	6440000	306700	7300	112200	0.0	2150500	0	2150500	53242100
20	3500	6440000	306700	7300	112200	0.0	2118000	0	2118000	55360100
21	1500	2760000	131400	3100	48100	0.0	1644400	0	1644400	57004500
22	1500	2760000	131400	3100	48100	0.0	1611900	0	1611900	58616400
23	1500	2760000	131400	3100	48100	0.0	1579400	0	1579400	60195800
24	1500	2760000	131400	3100	48100	0.0	1546900	0	1546900	61742700
25	1500	2760000	131400	3100	48100	0.0	1514400	0	1514400	63257100
26	1500	2760000	131400	3100	48100	0.0	1481900	0	1481900	64739000
27	1500	2760000	131400	3100	48100	0.0	1449400	0	1449400	66188400
28	1500	2760000	131400	3100	48100	0.0	1416900	0	1416900	67605300
29	1500	2760000	131400	3100	48100	0.0	1384400	0	1384400	68989700
30	1500	2760000	131400	3100	48100	0.0	1351900	0	1351900	70341600
TOT	127500	234600000	11171000	265500	4087500		70341600	0	70341600	

LIFETIME AVERAGE INCREASE (DECREASE) IN UNIT OPERATING COST			
DOLLARS PER TON OF COAL BURNED	6.30	0.0	6.30
MILLS PER KILOWATT-HOUR	2.76	0.0	2.76
CENTS PER MILLION BTU HEAT INPUT	29.98	0.0	29.98
DOLLARS PER TON OF SULFUR REMOVED	264.94	0.0	264.94
PROCESS COST DISCOUNTED AT 11.6% TO INITIAL YEAR, DOLLARS	23903700	0	23903700
LEVELIZED INCREASE (DECREASE) IN UNIT OPERATING COST EQUIVALENT TO DISCOUNTED PROCESS COST OVER LIFE OF POWER UNIT			
DOLLARS PER TON OF COAL BURNED	5.49	0.0	5.49
MILLS PER KILOWATT-HOUR	2.40	0.0	2.40
CENTS PER MILLION BTU HEAT INPUT	26.14	0.0	26.14
DOLLARS PER TON OF SULFUR REMOVED	230.73	0.0	230.73

TABLE B-2

LIME/LIMESTONE SLUDGE DISPOSAL - SLUDGE BLENDING PROCESS 500 MW NEW UNIT, 3.5% S IN FUEL, 16% ASH IN COAL, REGULATED CO. ECONOMICS

FIXED INVESTMENT: $ 8605000

YEARS AFTER POWER UNIT START	ANNUAL OPERATION, KW-HR/KW	POWER UNIT HEAT REQUIREMENT, MILLION BTU /YEAR	POWER UNIT FUEL CONSUMPTION, TONS COAL /YEAR	SULFUR REMOVED BY POLLUTION CONTROL PROCESS, TONS/YEAR	BY-PRODUCT RATE, EQUIVALENT TONS/YEAR WASTE SOLIDS	NET REVENUE, $/TON WASTE SOLIDS	TOTAL OP. COST INCLUDING REGULATED ROI FOR POWER COMPANY, $/YEAR	TOTAL NET SALES REVENUE, $/YEAR	NET ANNUAL INCREASE (DECREASE) IN COST OF POWER, $	CUMULATIVE NET INCREASE (DECREASE) IN COST OF POWER, $
1	7000	31500000	1500000	35600	548700	0.0	4514000	0	4514000	4514000
2	7000	31500000	1500000	35600	548700	0.0	4469500	0	4469500	8983500
3	7000	31500000	1500000	35600	548700	0.0	4425100	0	4425100	13408600
4	7000	31500000	1500000	35600	548700	0.0	4380700	0	4380700	17789300
5	7000	31500000	1500000	35600	548700	0.0	4336300	0	4336300	22125600
6	7000	31500000	1500000	35600	548700	0.0	4291900	0	4291900	26417500
7	7000	31500000	1500000	35600	548700	0.0	4247500	0	4247500	30665000
8	7000	31500000	1500000	35600	548700	0.0	4203100	0	4203100	34868100
9	7000	31500000	1500000	35600	548700	0.0	4158700	0	4158700	39026800
10	7000	31500000	1500000	35600	548700	0.0	4114300	0	4114300	43141100
11	5000	22500000	1071400	25400	392000	0.0	3657400	0	3657400	46798500
12	5000	22500000	1071400	25400	392000	0.0	3612900	0	3612900	50411400
13	5000	22500000	1071400	25400	392000	0.0	3568500	0	3568500	53979900
14	5000	22500000	1071400	25400	392000	0.0	3524100	0	3524100	57504000
15	5000	22500000	1071400	25400	392000	0.0	3479700	0	3479700	60983700
16	3500	15750000	750000	17800	274400	0.0	3080000	0	3080000	64063700
17	3500	15750000	750000	17800	274400	0.0	3035600	0	3035600	67099300
18	3500	15750000	750000	17800	274400	0.0	2991200	0	2991200	70090500
19	3500	15750000	750000	17800	274400	0.0	2946800	0	2946800	73037300
20	3500	15750000	750000	17800	274400	0.0	2902400	0	2902400	75939700
21	1500	6750000	321400	7600	117600	0.0	2258600	0	2258600	78198300
22	1500	6750000	321400	7600	117600	0.0	2214100	0	2214100	80412400
23	1500	6750000	321400	7600	117600	0.0	2169700	0	2169700	82582100
24	1500	6750000	321400	7600	117600	0.0	2125300	0	2125300	84707400
25	1500	6750000	321400	7600	117600	0.0	2080900	0	2080900	86788300
26	1500	6750000	321400	7600	117600	0.0	2036500	0	2036500	88824800
27	1500	6750000	321400	7600	117600	0.0	1992100	0	1992100	90816900
28	1500	6750000	321400	7600	117600	0.0	1947700	0	1947700	92764600
29	1500	6750000	321400	7600	117600	0.0	1903300	0	1903300	94667900
30	1500	6750000	321400	7600	117600	0.0	1858900	0	1858900	96526800
TOT	127500	573750000	27321000	648000	9995000		96526800	0	96526800	

LIFETIME AVERAGE INCREASE (DECREASE) IN UNIT OPERATING COST			
DOLLARS PER TON OF COAL BURNED	3.53	0.0	3.53
MILLS PER KILOWATT-HOUR	1.51	0.0	1.51
CENTS PER MILLION BTU HEAT INPUT	16.82	0.0	16.82
DOLLARS PER TON OF SULFUR REMOVED	148.96	0.0	148.96
PROCESS COST DISCOUNTED AT 11.6% TO INITIAL YEAR, DOLLARS	32801900	0	32801900
LEVELIZED INCREASE (DECREASE) IN UNIT OPERATING COST EQUIVALENT TO DISCOUNTED PROCESS COST OVER LIFE OF POWER UNIT			
DOLLARS PER TON OF COAL BURNED	3.08	0.0	3.08
MILLS PER KILOWATT-HOUR	1.32	0.0	1.32
CENTS PER MILLION BTU HEAT INPUT	14.67	0.0	14.67
DOLLARS PER TON OF SULFUR REMOVED	129.81	0.0	129.81

TABLE B-3

LIME/LIMESTONE SLUDGE DISPOSAL - SLUDGE BLENDING PROCESS 1500 MW NEW UNIT, 3.5% S IN FUEL, 16% ASH, REGULATED CO. ECONOMICS

FIXED INVESTMENT: $ 18282000

YEARS AFTER POWER UNIT START	ANNUAL OPERATION, KW-HR/KW	POWER UNIT HEAT REQUIREMENT, MILLION BTU /YEAR	POWER UNIT FUEL CONSUMPTION, TONS COAL /YEAR	SULFUR REMOVED BY POLLUTION CONTROL PROCESS, TONS/YEAR	BY-PRODUCT RATE, EQUIVALENT TONS/YEAR WASTE SOLIDS	NET REVENUE, $/TON WASTE SOLIDS	TOTAL OP. COST INCLUDING REGULATED ROI FOR POWER COMPANY, $/YEAR	TOTAL NET SALES REVENUE, $/YEAR	NET ANNUAL INCREASE (DECREASE) IN COST OF POWER, $	CUMULATIVE NET INCREASE (DECREASE) IN COST OF POWER, $
1	7000	94500000	4500000	106800	1646100	0.0	8534900	0	8534900	8534900
2	7000	94500000	4500000	106800	1646100	0.0	8442400	0	8442400	16977300
3	7000	94500000	4500000	106800	1646100	0.0	8349900	0	8349900	25327200
4	7000	94500000	4500000	106800	1646100	0.0	8257500	0	8257500	33584700
5	7000	94500000	4500000	106800	1646100	0.0	8165000	0	8165000	41749700
6	7000	94500000	4500000	106800	1646100	0.0	8072500	0	8072500	49822200
7	7000	94500000	4500000	106800	1646100	0.0	7980000	0	7980000	57802200
8	7000	94500000	4500000	106800	1646100	0.0	7887500	0	7887500	65689700
9	7000	94500000	4500000	106800	1646100	0.0	7795000	0	7795000	73484700
10	7000	94500000	4500000	106800	1646100	0.0	7702500	0	7702500	81187200
11	5000	67500000	3214300	76300	1175800	0.0	6870900	0	6870900	88058100
12	5000	67500000	3214300	76300	1175800	0.0	6778400	0	6778400	94836500
13	5000	67500000	3214300	76300	1175800	0.0	6685900	0	6685900	101522400
14	5000	67500000	3214300	76300	1175800	0.0	6593400	0	6593400	108115800
15	5000	67500000	3214300	76300	1175800	0.0	6500900	0	6500900	114616700
16	3500	47250000	2250000	53400	823100	0.0	5783800	0	5783800	120400500
17	3500	47250000	2250000	53400	823100	0.0	5691400	0	5691400	126091900
18	3500	47250000	2250000	53400	823100	0.0	5598900	0	5598900	131690800
19	3500	47250000	2250000	53400	823100	0.0	5506400	0	5506400	137197200
20	3500	47250000	2250000	53400	823100	0.0	5413900	0	5413900	142611100
21	1500	20250000	964300	22900	352700	0.0	4295600	0	4295600	146906700
22	1500	20250000	964300	22900	352700	0.0	4203100	0	4203100	151109800
23	1500	20250000	964300	22900	352700	0.0	4110600	0	4110600	155220400
24	1500	20250000	964300	22900	352700	0.0	4018200	0	4018200	159238600
25	1500	20250000	964300	22900	352700	0.0	3925700	0	3925700	163164300
26	1500	20250000	964300	22900	352700	0.0	3833200	0	3833200	166997500
27	1500	20250000	964300	22900	352700	0.0	3740700	0	3740700	170738200
28	1500	20250000	964300	22900	352700	0.0	3648200	0	3648200	174386400
29	1500	20250000	964300	22900	352700	0.0	3555700	0	3555700	177942100
30	1500	20250000	964300	22900	352700	0.0	3463300	0	3463300	181405400
TOT	127500	1721250000	81964500	1945500	29982500					
LIFETIME AVERAGE INCREASE (DECREASE) IN UNIT OPERATING COST							181405400	0	181405400	
DOLLARS PER TON OF COAL BURNED							2.21	0.0	2.21	
MILLS PER KILOWATT-HOUR							0.95	0.0	0.95	
CENTS PER MILLION BTU HEAT INPUT							10.54	0.0	10.54	
DOLLARS PER TON OF SULFUR REMOVED							93.24	0.0	93.24	
PROCESS COST DISCOUNTED AT 11.6% TO INITIAL YEAR, DOLLARS							61730100	0	61730100	
LEVELIZED INCREASE (DECREASE) IN UNIT OPERATING COST EQUIVALENT TO DISCOUNTED PROCESS COST OVER LIFE OF POWER UNIT										
DOLLARS PER TON OF COAL BURNED							1.93	0.0	1.93	
MILLS PER KILOWATT-HOUR							0.83	0.0	0.83	
CENTS PER MILLION BTU HEAT INPUT							9.20	0.0	9.20	
DOLLARS PER TON OF SULFUR REMOVED							81.41	0.0	81.41	

TABLE B-4

LIME/LIMESTONE SLUDGE DISPOSAL - GYPSUM PROCESS, 200 MW NEW UNIT, 3.5% S IN FUEL, 16% ASH IN COAL, REGULATED CO. ECONOMICS

FIXED INVESTMENT: $ 3988000

YEARS AFTER POWER UNIT START	ANNUAL OPERATION, KW-HR/KW	POWER UNIT HEAT REQUIREMENT, MILLION BTU /YEAR	POWER UNIT FUEL CONSUMPTION, TONS COAL /YEAR	SULFUR REMOVED BY POLLUTION CONTROL PROCESS, TONS/YEAR	BY-PRODUCT RATE, EQUIVALENT TONS/YEAR WASTE SOLIDS	NET REVENUE, $/TON WASTE SOLIDS	TOTAL OP. COST INCLUDING REGULATED ROI FOR POWER COMPANY, $/YEAR	TOTAL NET SALES REVENUE, $/YEAR	NET ANNUAL INCREASE (DECREASE) IN COST OF POWER, $	CUMULATIVE NET INCREASE (DECREASE) IN COST OF POWER, $
1	7000	12880000	613300	14100	203000	0.0	2864000	0	2864000	2864000
2	7000	12880000	613300	14100	203000	0.0	2843600	0	2843600	5707600
3	7000	12880000	613300	14100	203000	0.0	2823100	0	2823100	8530700
4	7000	12880000	613300	14100	203000	0.0	2802600	0	2802600	11333300
5	7000	12880000	613300	14100	203000	0.0	2782200	0	2782200	14115500
6	7000	12880000	613300	14100	203000	0.0	2761700	0	2761700	16877200
7	7000	12880000	613300	14100	203000	0.0	2741200	0	2741200	19618400
8	7000	12880000	613300	14100	203000	0.0	2720800	0	2720800	22339200
9	7000	12880000	613300	14100	203000	0.0	2700300	0	2700300	25039500
10	7000	12880000	613300	14100	203000	0.0	2679800	0	2679800	27719300
11	5000	9200000	438100	10100	145000	0.0	2348300	0	2348300	30067600
12	5000	9200000	438100	10100	145000	0.0	2327800	0	2327800	32395400
13	5000	9200000	438100	10100	145000	0.0	2307300	0	2307300	34702700
14	5000	9200000	438100	10100	145000	0.0	2286900	0	2286900	36989600
15	5000	9200000	438100	10100	145000	0.0	2266400	0	2266400	39256000
16	3500	6440000	306700	7100	101500	0.0	1974600	0	1974600	41230600
17	3500	6440000	306700	7100	101500	0.0	1954100	0	1954100	43184700
18	3500	6440000	306700	7100	101500	0.0	1933700	0	1933700	45118400
19	3500	6440000	306700	7100	101500	0.0	1913200	0	1913200	47031600
20	3500	6440000	306700	7100	101500	0.0	1892700	0	1892700	48924300
21	1500	2760000	131400	3000	43500	0.0	1406000	0	1406000	50330300
22	1500	2760000	131400	3000	43500	0.0	1385500	0	1385500	51715800
23	1500	2760000	131400	3000	43500	0.0	1365000	0	1365000	53080800
24	1500	2760000	131400	3000	43500	0.0	1344600	0	1344600	54425400
25	1500	2760000	131400	3000	43500	0.0	1324100	0	1324100	55749500
26	1500	2760000	131400	3000	43500	0.0	1303600	0	1303600	57053100
27	1500	2760000	131400	3000	43500	0.0	1283200	0	1283200	58336300
28	1500	2760000	131400	3000	43500	0.0	1262700	0	1262700	59599000
29	1500	2760000	131400	3000	43500	0.0	1242200	0	1242200	60841200
30	1500	2760000	131400	3000	43500	0.0	1221800	0	1221800	62063000
TOT	127500	234600000	11171000	257000	3697500		62063000	0	62063000	
LIFETIME AVERAGE INCREASE (DECREASE) IN UNIT OPERATING COST										
DOLLARS PER TON OF COAL BURNED							5.56	0.0	5.56	
MILLS PER KILOWATT-HOUR							2.43	0.0	2.43	
CENTS PER MILLION BTU HEAT INPUT							26.45	0.0	26.45	
DOLLARS PER TON OF SULFUR REMOVED							241.49	0.0	241.49	
PROCESS COST DISCOUNTED AT 11.6% TO INITIAL YEAR, DOLLARS							21047100	0	21047100	
LEVELIZED INCREASE (DECREASE) IN UNIT OPERATING COST EQUIVALENT TO DISCOUNTED PROCESS COST OVER LIFE OF POWER UNIT										
DOLLARS PER TON OF COAL BURNED							4.83	0.0	4.83	
MILLS PER KILOWATT-HOUR							2.12	0.0	2.12	
CENTS PER MILLION BTU HEAT INPUT							23.02	0.0	23.02	
DOLLARS PER TON OF SULFUR REMOVED							210.26	0.0	210.26	

TABLE B-5

LIME/LIMESTONE SLUDGE DISPOSAL - GYPSUM PROCESS. 500 MW NEW UNIT. 3.5% S IN FUEL. 16% ASH IN COAL. REGULATED CO. ECONOMICS

FIXED INVESTMENT: $ 5411000

YEARS AFTER POWER UNIT START	ANNUAL OPERATION, KW-HR/ KW	POWER UNIT HEAT REQUIREMENT, MILLION BTU /YEAR	POWER UNIT FUEL CONSUMPTION, TONS COAL /YEAR	SULFUR REMOVED BY POLLUTION CONTROL PROCESS, TONS/YEAR	BY-PRODUCT RATE, EQUIVALENT TONS/YEAR WASTE SOLIDS	NET REVENUE, $/TON WASTE SOLIDS	TOTAL OP. COST INCLUDING REGULATED ROI FOR POWER COMPANY, $/YEAR	TOTAL NET SALES REVENUE, $/YEAR	NET ANNUAL INCREASE (DECREASE) IN COST OF POWER, $	CUMULATIVE NET INCREASE (DECREASE) IN COST OF POWER, $
1	7000	31500000	1500000	35700	496300	0.0	3615300	0	3615300	3615300
2	7000	31500000	1500000	35700	496300	0.0	3588300	0	3588300	7203600
3	7000	31500000	1500000	35700	496300	0.0	3561400	0	3561400	10765000
4	7000	31500000	1500000	35700	496300	0.0	3534400	0	3534400	14299400
5	7000	31500000	1500000	35700	496300	0.0	3507500	0	3507500	17806900
6	7000	31500000	1500000	35700	496300	0.0	3480500	0	3480500	21287400
7	7000	31500000	1500000	35700	496300	0.0	3453600	0	3453600	24741000
8	7000	31500000	1500000	35700	496300	0.0	3426600	0	3426600	28167600
9	7000	31500000	1500000	35700	496300	0.0	3399700	0	3399700	31567300
10	7000	31500000	1500000	35700	496300	0.0	3372700	0	3372700	34940000
11	5000	22500000	1071400	25500	354500	0.0	2952700	0	2952700	37892700
12	5000	22500000	1071400	25500	354500	0.0	2925700	0	2925700	40818400
13	5000	22500000	1071400	25500	354500	0.0	2898800	0	2898800	43717200
14	5000	22500000	1071400	25500	354500	0.0	2871800	0	2871800	46589000
15	5000	22500000	1071400	25500	354500	0.0	2844900	0	2844900	49433900
16	3500	15750000	750000	17900	248200	0.0	2479100	0	2479100	51913000
17	3500	15750000	750000	17900	248200	0.0	2452200	0	2452200	54365200
18	3500	15750000	750000	17900	248200	0.0	2425200	0	2425200	56790400
19	3500	15750000	750000	17900	248200	0.0	2398200	0	2398200	59188600
20	3500	15750000	750000	17900	248200	0.0	2371300	0	2371300	61559900
21	1500	6750000	321400	7700	106400	0.0	1772500	0	1772500	63332400
22	1500	6750000	321400	7700	106400	0.0	1745600	0	1745600	65078000
23	1500	6750000	321400	7700	106400	0.0	1718600	0	1718600	66796600
24	1500	6750000	321400	7700	106400	0.0	1691700	0	1691700	68488300
25	1500	6750000	321400	7700	106400	0.0	1664700	0	1664700	70153000
26	1500	6750000	321400	7700	106400	0.0	1637800	0	1637800	71790800
27	1500	6750000	321400	7700	106400	0.0	1610800	0	1610800	73401600
28	1500	6750000	321400	7700	106400	0.0	1583900	0	1583900	74985500
29	1500	6750000	321400	7700	106400	0.0	1556900	0	1556900	76542400
30	1500	6750000	321400	7700	106400	0.0	1530000	0	1530000	78072400
TOT	127500	573750000	27321000	651000	9040500		78072400	0	78072400	
LIFETIME AVERAGE INCREASE (DECREASE) IN UNIT OPERATING COST										
DOLLARS PER TON OF COAL BURNED							2.86	0.0	2.86	
MILLS PER KILOWATT-HOUR							1.22	0.0	1.22	
CENTS PER MILLION BTU HEAT INPUT							13.61	0.0	13.61	
DOLLARS PER TON OF SULFUR REMOVED							119.93	0.0	119.93	
PROCESS COST DISCOUNTED AT 11.6% TO INITIAL YEAR, DOLLARS							26513400	0	26513400	
LEVELIZED INCREASE (DECREASE) IN UNIT OPERATING COST EQUIVALENT TO DISCOUNTED PROCESS COST OVER LIFE OF POWER UNIT										
DOLLARS PER TON OF COAL BURNED							2.49	0.0	2.49	
MILLS PER KILOWATT-HOUR							1.07	0.0	1.07	
CENTS PER MILLION BTU HEAT INPUT							11.86	0.0	11.86	
DOLLARS PER TON OF SULFUR REMOVED							104.59	0.0	104.59	

TABLE B-6

LIME/LIMESTONE SLUDGE DISPOSAL - GYPSUM PROCESS, 1500 MW NEW UNIT, 3.5% S IN FUEL, 16% ASH IN COAL, REGULATED CO. ECONOMICS

FIXED INVESTMENT: $ 9826000

YEARS AFTER POWER UNIT START	ANNUAL OPERATION, KW-HR/KW	POWER UNIT HEAT REQUIREMENT, MILLION BTU /YEAR	POWER UNIT FUEL CONSUMPTION, TONS COAL /YEAR	SULFUR REMOVED BY POLLUTION CONTROL PROCESS, TONS/YEAR	BY-PRODUCT RATE, EQUIVALENT TONS/YEAR WASTE SOLIDS	NET REVENUE, $/TON WASTE SOLIDS	TOTAL OP. COST INCLUDING REGULATED ROI FOR POWER COMPANY, $/YEAR	TOTAL NET SALES REVENUE, $/YEAR	NET ANNUAL INCREASE (DECREASE) IN COST OF POWER, $	CUMULATIVE NET INCREASE (DECREASE) IN COST OF POWER, $
1	7000	94500000	4500000	106800	1488200	0.0	5881800	0	5881800	5881800
2	7000	94500000	4500000	106800	1488200	0.0	5835000	0	5835000	11716800
3	7000	94500000	4500000	106800	1488200	0.0	5788200	0	5788200	17505000
4	7000	94500000	4500000	106800	1488200	0.0	5741500	0	5741500	23246500
5	7000	94500000	4500000	106800	1488200	0.0	5694700	0	5694700	28941200
6	7000	94500000	4500000	106800	1488200	0.0	5647900	0	5647900	34589100
7	7000	94500000	4500000	106800	1488200	0.0	5601200	0	5601200	40190300
8	7000	94500000	4500000	106800	1488200	0.0	5554400	0	5554400	45744700
9	7000	94500000	4500000	106800	1488200	0.0	5507600	0	5507600	51252300
10	7000	94500000	4500000	106800	1488200	0.0	5460900	0	5460900	56713200
11	5000	67500000	3214300	76300	1063000	0.0	4774400	0	4774400	61487600
12	5000	67500000	3214300	76300	1063000	0.0	4727600	0	4727600	66215200
13	5000	67500000	3214300	76300	1063000	0.0	4680900	0	4680900	70896100
14	5000	67500000	3214300	76300	1063000	0.0	4634100	0	4634100	75530200
15	5000	67500000	3214300	76300	1063000	0.0	4587300	0	4587300	80117500
16	3500	47250000	2250000	53400	744100	0.0	4000600	0	4000600	84118100
17	3500	47250000	2250000	53400	744100	0.0	3953800	0	3953800	88071900
18	3500	47250000	2250000	53400	744100	0.0	3907000	0	3907000	91978900
19	3500	47250000	2250000	53400	744100	0.0	3860300	0	3860300	95839200
20	3500	47250000	2250000	53400	744100	0.0	3813500	0	3813500	99652700
21	1500	20250000	964300	22900	318900	0.0	2882700	0	2882700	102535400
22	1500	20250000	964300	22900	318900	0.0	2836000	0	2836000	105371400
23	1500	20250000	964300	22900	318900	0.0	2789200	0	2789200	108160600
24	1500	20250000	964300	22900	318900	0.0	2742400	0	2742400	110903000
25	1500	20250000	964300	22900	318900	0.0	2695700	0	2695700	113598700
26	1500	20250000	964300	22900	318900	0.0	2648900	0	2648900	116247600
27	1500	20250000	964300	22900	318900	0.0	2602100	0	2602100	118849700
28	1500	20250000	964300	22900	318900	0.0	2555400	0	2555400	121405100
29	1500	20250000	964300	22900	318900	0.0	2508600	0	2508600	123913700
30	1500	20250000	964300	22900	318900	0.0	2461800	0	2461800	126375500
TOT	127500	1721250000	81964500	1945500	27106500		126375500	0	126375500	
LIFETIME AVERAGE INCREASE (DECREASE) IN UNIT OPERATING COST										
DOLLARS PER TON OF COAL BURNED							1.54	0.0	1.54	
MILLS PER KILOWATT-HOUR							0.66	0.0	0.66	
CENTS PER MILLION BTU HEAT INPUT							7.34	0.0	7.34	
DOLLARS PER TON OF SULFUR REMOVED							64.96	0.0	64.96	
PROCESS COST DISCOUNTED AT 11.6% TO INITIAL YEAR, DOLLARS							42998600	0	42998600	
LEVELIZED INCREASE (DECREASE) IN UNIT OPERATING COST EQUIVALENT TO DISCOUNTED PROCESS COST OVER LIFE OF POWER UNIT										
DOLLARS PER TON OF COAL BURNED							1.35	0.0	1.35	
MILLS PER KILOWATT-HOUR							0.58	0.0	0.58	
CENTS PER MILLION BTU HEAT INPUT							6.41	0.0	6.41	
DOLLARS PER TON OF SULFUR REMOVED							56.70	0.0	56.70	

APPENDIX C

CONSTANT ON-STREAM TIME - LIFETIME REVENUE REQUIREMENTS

Preceding page blank

TABLE C-1

LIME/LIMESTONE SLUDGE DISPOSAL - SLUDGE BLENDING PROCESS, 200 MW NEW UNIT, 3.5% S, 7000 HRS CONSTANT ONSTREAM, REGULATED CO. ECONO

FIXED INVESTMENT: $ 6268000

YEARS AFTER POWER UNIT START	ANNUAL OPERATION, KW-HR/KW	POWER UNIT HEAT REQUIREMENT, MILLION BTU /YEAR	POWER UNIT FUEL CONSUMPTION, TONS COAL /YEAR	SULFUR REMOVED BY POLLUTION CONTROL PROCESS, TONS/YEAR	BY-PRODUCT RATE, EQUIVALENT TONS/YEAR WASTE SOLIDS	NET REVENUE, $/TON WASTE SOLIDS	TOTAL OP. COST INCLUDING REGULATED ROI FOR POWER COMPANY, $/YEAR	TOTAL NET SALES REVENUE, $/YEAR	NET ANNUAL INCREASE (DECREASE) IN COST OF POWER, $	CUMULATIVE NET INCREASE (DECREASE) IN COST OF POWER, $
1	7000	12880000	613300	14600	224400	0.0	3320200	0	3320200	3320200
2	7000	12880000	613300	14600	224400	0.0	3287700	0	3287700	6607900
3	7000	12880000	613300	14600	224400	0.0	3255200	0	3255200	9863100
4	7000	12880000	613300	14600	224400	0.0	3222700	0	3222700	13085800
5	7000	12880000	613300	14600	224400	0.0	3190200	0	3190200	16276000
6	7000	12880000	613300	14600	224400	0.0	3157700	0	3157700	19433700
7	7000	12880000	613300	14600	224400	0.0	3125300	0	3125300	22559000
8	7000	12880000	613300	14600	224400	0.0	3092800	0	3092800	25651800
9	7000	12880000	613300	14600	224400	0.0	3060300	0	3060300	28712100
10	7000	12880000	613300	14600	224400	0.0	3027800	0	3027800	31739900
11	7000	12880000	613300	14600	224400	0.0	2995300	0	2995300	34735200
12	7000	12880000	613300	14600	224400	0.0	2962800	0	2962800	37698000
13	7000	12880000	613300	14600	224400	0.0	2930300	0	2930300	40628300
14	7000	12880000	613300	14600	224400	0.0	2897800	0	2897800	43526100
15	7000	12880000	613300	14600	224400	0.0	2865300	0	2865300	46391400
16	7000	12880000	613300	14600	224400	0.0	2832800	0	2832800	49224200
17	7000	12880000	613300	14600	224400	0.0	2800300	0	2800300	52024500
18	7000	12880000	613300	14600	224400	0.0	2767900	0	2767900	54792400
19	7000	12880000	613300	14600	224400	0.0	2735400	0	2735400	57527800
20	7000	12880000	613300	14600	224400	0.0	2702900	0	2702900	60230700
21	7000	12880000	613300	14600	224400	0.0	2670400	0	2670400	62901100
22	7000	12880000	613300	14600	224400	0.0	2637900	0	2637900	65539000
23	7000	12880000	613300	14600	224400	0.0	2605400	0	2605400	68144400
24	7000	12880000	613300	14600	224400	0.0	2572900	0	2572900	70717300
25	7000	12880000	613300	14600	224400	0.0	2540400	0	2540400	73257700
26	7000	12880000	613300	14600	224400	0.0	2507900	0	2507900	75765600
27	7000	12880000	613300	14600	224400	0.0	2475400	0	2475400	78241000
28	7000	12880000	613300	14600	224400	0.0	2442900	0	2442900	80683900
29	7000	12880000	613300	14600	224400	0.0	2410500	0	2410500	83094400
30	7000	12880000	613300	14600	224400	0.0	2378000	0	2378000	85472400
TOT	210000	386400000	18399000	438000	6732000		85472400	0	85472400	

LIFETIME AVERAGE INCREASE (DECREASE) IN UNIT OPERATING COST			
DOLLARS PER TON OF COAL BURNED	4.65	0.0	4.65
MILLS PER KILOWATT-HOUR	2.04	0.0	2.04
CENTS PER MILLION BTU HEAT INPUT	22.12	0.0	22.12
DOLLARS PER TON OF SULFUR REMOVED	195.14	0.0	195.14
PROCESS COST DISCOUNTED AT 11.6% TO INITIAL YEAR, DOLLARS	25546100	0	25546100
LEVELIZED INCREASE (DECREASE) IN UNIT OPERATING COST EQUIVALENT TO DISCOUNTED PROCESS COST OVER LIFE OF POWER UNIT			
DOLLARS PER TON OF COAL BURNED	5.02	0.0	5.02
MILLS PER KILOWATT-HOUR	2.20	0.0	2.20
CENTS PER MILLION BTU HEAT INPUT	23.90	0.0	23.90
DOLLARS PER TON OF SULFUR REMOVED	210.78	0.0	210.78

TABLE C-2

LIME/LIMESTONE SLUDGE DISPOSAL - SLUDGE BLENDING PROCESS, 500 MW NEW UNIT, 3.5% S, 7000 HRS CONSTANT ONSTREAM, REGULATED CO. ECONO

FIXED INVESTMENT: $ 8955000

YEARS AFTER POWER UNIT START	ANNUAL OPERATION, KW-HR/KW	POWER UNIT HEAT REQUIREMENT, MILLION BTU /YEAR	POWER UNIT FUEL CONSUMPTION, TONS COAL /YEAR	SULFUR REMOVED BY POLLUTION CONTROL PROCESS, TONS/YEAR	BY-PRODUCT RATE, EQUIVALENT TONS/YEAR WASTE SOLIDS	NET REVENUE, $/TON WASTE SOLIDS	TOTAL OP. COST INCLUDING REGULATED ROI FOR POWER COMPANY, $/YEAR	TOTAL NET SALES REVENUE, $/YEAR	NET ANNUAL INCREASE (DECREASE) IN COST OF POWER, $	CUMULATIVE NET INCREASE (DECREASE) IN COST OF POWER, $
1	7000	31500000	1500000	35600	496300	0.0	4590500	0	4590500	4590500
2	7000	31500000	1500000	35600	496300	0.0	4546000	0	4546000	9136500
3	7000	31500000	1500000	35600	496300	0.0	4501600	0	4501600	13638100
4	7000	31500000	1500000	35600	496300	0.0	4457200	0	4457200	18095300
5	7000	31500000	1500000	35600	496300	0.0	4412800	0	4412800	22508100
6	7000	31500000	1500000	35600	496300	0.0	4368400	0	4368400	26876500
7	7000	31500000	1500000	35600	496300	0.0	4324000	0	4324000	31200500
8	7000	31500000	1500000	35600	496300	0.0	4279600	0	4279600	35480100
9	7000	31500000	1500000	35600	496300	0.0	4235200	0	4235200	39715300
10	7000	31500000	1500000	35600	496300	0.0	4190800	0	4190800	43906100
11	7000	31500000	1500000	35600	496300	0.0	4146400	0	4146400	48052500
12	7000	31500000	1500000	35600	496300	0.0	4101900	0	4101900	52154400
13	7000	31500000	1500000	35600	496300	0.0	4057500	0	4057500	56211900
14	7000	31500000	1500000	35600	496300	0.0	4013100	0	4013100	60225000
15	7000	31500000	1500000	35600	496300	0.0	3968700	0	3968700	64193700
16	7000	31500000	1500000	35600	496300	0.0	3924300	0	3924300	68118000
17	7000	31500000	1500000	35600	496300	0.0	3879900	0	3879900	71997900
18	7000	31500000	1500000	35600	496300	0.0	3835500	0	3835500	75833400
19	7000	31500000	1500000	35600	496300	0.0	3791100	0	3791100	79624500
20	7000	31500000	1500000	35600	496300	0.0	3746700	0	3746700	83371200
21	7000	31500000	1500000	35600	496300	0.0	3702300	0	3702300	87073500
22	7000	31500000	1500000	35600	496300	0.0	3657800	0	3657800	90731300
23	7000	31500000	1500000	35600	496300	0.0	3613400	0	3613400	94344700
24	7000	31500000	1500000	35600	496300	0.0	3569000	0	3569000	97913700
25	7000	31500000	1500000	35600	496300	0.0	3524600	0	3524600	101438300
26	7000	31500000	1500000	35600	496300	0.0	3480200	0	3480200	104918500
27	7000	31500000	1500000	35600	496300	0.0	3435800	0	3435800	108354300
28	7000	31500000	1500000	35600	496300	0.0	3391400	0	3391400	111745700
29	7000	31500000	1500000	35600	496300	0.0	3347000	0	3347000	115092700
30	7000	31500000	1500000	35600	496300	0.0	3302600	0	3302600	118395300
TOT	210000	945000000	45000000	1068000	14889000		118395300	0	118395300	

LIFETIME AVERAGE INCREASE (DECREASE) IN UNIT OPERATING COST	TOTAL OP. COST	TOTAL NET SALES REVENUE	NET ANNUAL INCREASE
DOLLARS PER TON OF COAL BURNED	2.63	0.0	2.63
MILLS PER KILOWATT-HOUR	1.13	0.0	1.13
CENTS PER MILLION BTU HEAT INPUT	12.53	0.0	12.53
DOLLARS PER TON OF SULFUR REMOVED	110.86	0.0	110.86
PROCESS COST DISCOUNTED AT 11.6% TO INITIAL YEAR, DOLLARS	35351400	0	35351400
LEVELIZED INCREASE (DECREASE) IN UNIT OPERATING COST EQUIVALENT TO DISCOUNTED PROCESS COST OVER LIFE OF POWER UNIT			
DOLLARS PER TON OF COAL BURNED	2.84	0.0	2.84
MILLS PER KILOWATT-HOUR	1.22	0.0	1.22
CENTS PER MILLION BTU HEAT INPUT	13.52	0.0	13.52
DOLLARS PER TON OF SULFUR REMOVED	119.63	0.0	119.63

TABLE C-3

LIME/LIMESTONE SLUDGE DISPOSAL - SLUDGE BLENDING PROCESS, 1500 MW NEW UNIT, 3.5% S, 7000 HRS CONSTANT ONSTREAM, REGULATED CO. ECON

FIXED INVESTMENT: $ 19321000

YEARS AFTER POWER UNIT START	ANNUAL OPERATION, KW-HR/KW	POWER UNIT HEAT REQUIREMENT, MILLION BTU /YEAR	POWER UNIT FUEL CONSUMPTION, TONS COAL /YEAR	SULFUR REMOVED BY POLLUTION CONTROL PROCESS, TONS/YEAR	BY-PRODUCT RATE, EQUIVALENT TONS/YEAR WASTE SOLIDS	NET REVENUE, $/TON WASTE SOLIDS	TOTAL OP. COST INCLUDING REGULATED ROI FOR POWER COMPANY, $/YEAR	TOTAL NET SALES REVENUE, $/YEAR	NET ANNUAL INCREASE (DECREASE) IN COST OF POWER, $	CUMULATIVE NET INCREASE (DECREASE) IN COST OF POWER, $
1	7000	94500000	4500000	106800	1646100	0.0	8760900	0	8760900	8760900
2	7000	94500000	4500000	106800	1646100	0.0	8668400	0	8668400	17429300
3	7000	94500000	4500000	106800	1646100	0.0	8575900	0	8575900	26005200
4	7000	94500000	4500000	106800	1646100	0.0	8483500	0	8483500	34488700
5	7000	94500000	4500000	106800	1646100	0.0	8391000	0	8391000	42879700
6	7000	94500000	4500000	106800	1646100	0.0	8298500	0	8298500	51178200
7	7000	94500000	4500000	106800	1646100	0.0	8206000	0	8206000	59384200
8	7000	94500000	4500000	106800	1646100	0.0	8113500	0	8113500	67497700
9	7000	94500000	4500000	106800	1646100	0.0	8021000	0	8021000	75518700
10	7000	94500000	4500000	106800	1646100	0.0	7928600	0	7928600	83447300
11	7000	94500000	4500000	106800	1646100	0.0	7836100	0	7836100	91283400
12	7000	94500000	4500000	106800	1646100	0.0	7743600	0	7743600	99027000
13	7000	94500000	4500000	106800	1646100	0.0	7651100	0	7651100	106678100
14	7000	94500000	4500000	106800	1646100	0.0	7558600	0	7558600	114236700
15	7000	94500000	4500000	106800	1646100	0.0	7466100	0	7466100	121702800
16	7000	94500000	4500000	106800	1646100	0.0	7373600	0	7373600	129076400
17	7000	94500000	4500000	106800	1646100	0.0	7281200	0	7281200	136357600
18	7000	94500000	4500000	106800	1646100	0.0	7188700	0	7188700	143546300
19	7000	94500000	4500000	106800	1646100	0.0	7096200	0	7096200	150642500
20	7000	94500000	4500000	106800	1646100	0.0	7003700	0	7003700	157646200
21	7000	94500000	4500000	106800	1646100	0.0	6911200	0	6911200	164557400
22	7000	94500000	4500000	106800	1646100	0.0	6818700	0	6818700	171376100
23	7000	94500000	4500000	106800	1646100	0.0	6726300	0	6726300	178102400
24	7000	94500000	4500000	106800	1646100	0.0	6633800	0	6633800	184736200
25	7000	94500000	4500000	106800	1646100	0.0	6541300	0	6541300	191277500
26	7000	94500000	4500000	106800	1646100	0.0	6448800	0	6448800	197726300
27	7000	94500000	4500000	106800	1646100	0.0	6356300	0	6356300	204082600
28	7000	94500000	4500000	106800	1646100	0.0	6263800	0	6263800	210346400
29	7000	94500000	4500000	106800	1646100	0.0	6171300	0	6171300	216517700
30	7000	94500000	4500000	106800	1646100	0.0	6078900	0	6078900	222596600
TOT	210000	28350000000	135000000	3204000	49383000					
LIFETIME AVERAGE INCREASE (DECREASE) IN UNIT OPERATING COST							222596600	0	222596600	
DOLLARS PER TON OF COAL BURNED										
MILLS PER KILOWATT-HOUR							1.65	0.0	1.65	
CENTS PER MILLION BTU HEAT INPUT							0.71	0.0	0.71	
DOLLARS PER TON OF SULFUR REMOVED							7.85	0.0	7.85	
PROCESS COST DISCOUNTED AT 11.6% TO INITIAL YEAR, DOLLARS							69.47	0.0	69.47	
LEVELIZED INCREASE (DECREASE) IN UNIT OPERATING COST EQUIVALENT TO DISCOUNTED PROCESS COST OVER LIFE OF POWER UNIT							66989700	0	66989700	
DOLLARS PER TON OF COAL BURNED										
MILLS PER KILOWATT-HOUR							1.79	0.0	1.79	
CENTS PER MILLION BTU HEAT INPUT							0.77	0.0	0.77	
DOLLARS PER TON OF SULFUR REMOVED							8.54	0.0	8.54	
							75.57	0.0	75.57	

TABLE C-4

LIME/LIMESTONE SLUDGE DISPOSAL - GYPSUM PROCESS, 200 MW NEW UNIT, 3.5% S, 7000 HRS CONSTANT ONSTREAM, REGULATED CO. ECONOMICS

FIXED INVESTMENT: $ 4093000

YEARS AFTER POWER UNIT START	ANNUAL OPERATION, KW-HR/ KW	POWER UNIT HEAT REQUIREMENT, MILLION BTU /YEAR	POWER UNIT FUEL CONSUMPTION, TONS COAL /YEAR	SULFUR REMOVED BY POLLUTION CONTROL PROCESS, TONS/YEAR	BY-PRODUCT RATE, EQUIVALENT TONS/YEAR WASTE SOLIDS	NET REVENUE, $/TON WASTE SOLIDS	TOTAL OP. COST INCLUDING REGULATED ROI FOR POWER COMPANY, $/YEAR	TOTAL NET SALES REVENUE, $/YEAR	NET ANNUAL INCREASE (DECREASE) IN COST OF POWER, $	CUMULATIVE NET INCREASE (DECREASE) IN COST OF POWER, $
1	7000	12880000	613300	14100	203000	0.0	2886500	0	2886500	2886500
2	7000	12880000	613300	14100	203000	0.0	2866000	0	2866000	5752500
3	7000	12880000	613300	14100	203000	0.0	2845600	0	2845600	8598100
4	7000	12880000	613300	14100	203000	0.0	2825100	0	2825100	11423200
5	7000	12880000	613300	14100	203000	0.0	2804600	0	2804600	14227800
6	7000	12880000	613300	14100	203000	0.0	2784200	0	2784200	17012000
7	7000	12880000	613300	14100	203000	0.0	2763700	0	2763700	19775700
8	7000	12880000	613300	14100	203000	0.0	2743200	0	2743200	22518900
9	7000	12880000	613300	14100	203000	0.0	2722800	0	2722800	25241700
10	7000	12880000	613300	14100	203000	0.0	2702300	0	2702300	27944000
11	7000	12880000	613300	14100	203000	0.0	2681800	0	2681800	30625800
12	7000	12880000	613300	14100	203000	0.0	2661300	0	2661300	33287100
13	7000	12880000	613300	14100	203000	0.0	2640900	0	2640900	35928000
14	7000	12880000	613300	14100	203000	0.0	2620400	0	2620400	38548400
15	7000	12880000	613300	14100	203000	0.0	2599900	0	2599900	41148300
16	7000	12880000	613300	14100	203000	0.0	2579500	0	2579500	43727800
17	7000	12880000	613300	14100	203000	0.0	2559000	0	2559000	46286800
18	7000	12880000	613300	14100	203000	0.0	2538500	0	2538500	48825300
19	7000	12880000	613300	14100	203000	0.0	2518100	0	2518100	51343400
20	7000	12880000	613300	14100	203000	0.0	2497600	0	2497600	53841000
21	7000	12880000	613300	14100	203000	0.0	2477100	0	2477100	56318100
22	7000	12880000	613300	14100	203000	0.0	2456700	0	2456700	58774800
23	7000	12880000	613300	14100	203000	0.0	2436200	0	2436200	61211000
24	7000	12880000	613300	14100	203000	0.0	2415700	0	2415700	63626700
25	7000	12880000	613300	14100	203000	0.0	2395300	0	2395300	66022000
26	7000	12880000	613300	14100	203000	0.0	2374800	0	2374800	68396800
27	7000	12880000	613300	14100	203000	0.0	2354300	0	2354300	70751100
28	7000	12880000	613300	14100	203000	0.0	2333900	0	2333900	73085000
29	7000	12880000	613300	14100	203000	0.0	2313400	0	2313400	75398400
30	7000	12880000	613300	14100	203000	0.0	2292900	0	2292900	77691300
TOT	210000	386400000	18399000	423000	6090000		77691300	0	77691300	
LIFETIME AVERAGE INCREASE (DECREASE) IN UNIT OPERATING COST										
DOLLARS PER TON OF COAL BURNED							4.22	0.0	4.22	
MILLS PER KILOWATT-HOUR							1.85	0.0	1.85	
CENTS PER MILLION BTU HEAT INPUT							20.11	0.0	20.11	
DOLLARS PER TON OF SULFUR REMOVED							183.67	0.0	183.67	
PROCESS COST DISCOUNTED AT 11.6% TO INITIAL YEAR, DOLLARS							22691000	0	22691000	
LEVELIZED INCREASE (DECREASE) IN UNIT OPERATING COST EQUIVALENT TO DISCOUNTED PROCESS COST OVER LIFE OF POWER UNIT										
DOLLARS PER TON OF COAL BURNED							4.46	0.0	4.46	
MILLS PER KILOWATT-HOUR							1.95	0.0	1.95	
CENTS PER MILLION BTU HEAT INPUT							21.22	0.0	21.22	
DOLLARS PER TON OF SULFUR REMOVED							193.94	0.0	193.94	

Reproduced from
best available copy.

TABLE C-5

LIME/LIMESTONE SLUDGE DISPOSAL - GYPSUM PROCESS, 500 MW NEW UNIT, 3.5% S, 7000 HRS CONSTANT ONSTREAM, REGULATED CO. ECONOMICS

FIXED INVESTMENT: $ 5667000

YEARS AFTER POWER UNIT START	ANNUAL OPERATION, KW-HR/KW	POWER UNIT HEAT REQUIREMENT, MILLION BTU /YEAR	POWER UNIT FUEL CONSUMPTION, TONS COAL /YEAR	SULFUR REMOVED BY POLLUTION CONTROL PROCESS, TONS/YEAR	BY-PRODUCT RATE, EQUIVALENT TONS/YEAR WASTE SOLIDS	NET REVENUE, $/TON WASTE SOLIDS	TOTAL OP. COST INCLUDING REGULATED ROI FOR POWER COMPANY, $/YEAR	TOTAL NET SALES REVENUE, $/YEAR	NET ANNUAL INCREASE (DECREASE) IN COST OF POWER, $	CUMULATIVE NET INCREASE (DECREASE) IN COST OF POWER, $
1	7000	31500000	1500000	35700	496300	0.0	3670900	0	3670900	3670900
2	7000	31500000	1500000	35700	496300	0.0	3644000	0	3644000	7314900
3	7000	31500000	1500000	35700	496300	0.0	3617000	0	3617000	10931900
4	7000	31500000	1500000	35700	496300	0.0	3590100	0	3590100	14522000
5	7000	31500000	1500000	35700	496300	0.0	3563100	0	3563100	18085100
6	7000	31500000	1500000	35700	496300	0.0	3536200	0	3536200	21621300
7	7000	31500000	1500000	35700	496300	0.0	3509200	0	3509200	25130500
8	7000	31500000	1500000	35700	496300	0.0	3482300	0	3482300	28612800
9	7000	31500000	1500000	35700	496300	0.0	3455300	0	3455300	32068100
10	7000	31500000	1500000	35700	496300	0.0	3428400	0	3428400	35496500
11	7000	31500000	1500000	35700	496300	0.0	3401400	0	3401400	38897900
12	7000	31500000	1500000	35700	496300	0.0	3374400	0	3374400	42272300
13	7000	31500000	1500000	35700	496300	0.0	3347500	0	3347500	45619800
14	7000	31500000	1500000	35700	496300	0.0	3320500	0	3320500	48940300
15	7000	31500000	1500000	35700	496300	0.0	3293600	0	3293600	52233900
16	7000	31500000	1500000	35700	496300	0.0	3266600	0	3266600	55500500
17	7000	31500000	1500000	35700	496300	0.0	3239700	0	3239700	58740200
18	7000	31500000	1500000	35700	496300	0.0	3212700	0	3212700	61952900
19	7000	31500000	1500000	35700	496300	0.0	3185800	0	3185800	65138700
20	7000	31500000	1500000	35700	496300	0.0	3158800	0	3158800	68297500
21	7000	31500000	1500000	35700	496300	0.0	3131900	0	3131900	71429400
22	7000	31500000	1500000	35700	496300	0.0	3104900	0	3104900	74534300
23	7000	31500000	1500000	35700	496300	0.0	3078000	0	3078000	77612300
24	7000	31500000	1500000	35700	496300	0.0	3051000	0	3051000	80663300
25	7000	31500000	1500000	35700	496300	0.0	3024100	0	3024100	83687400
26	7000	31500000	1500000	35700	496300	0.0	2997100	0	2997100	86684500
27	7000	31500000	1500000	35700	496300	0.0	2970200	0	2970200	89654700
28	7000	31500000	1500000	35700	496300	0.0	2943200	0	2943200	92597900
29	7000	31500000	1500000	35700	496300	0.0	2916300	0	2916300	95514200
30	7000	31500000	1500000	35700	496300	0.0	2889300	0	2889300	98403500
TOT	210000	945000000	45000000	1071000	14889000		98403500	0	98403500	
LIFETIME AVERAGE INCREASE (DECREASE) IN UNIT OPERATING COST										
DOLLARS PER TON OF COAL BURNED							2.19	0.0	2.19	
MILLS PER KILOWATT-HOUR							0.94	0.0	0.94	
CENTS PER MILLION BTU HEAT INPUT							10.41	0.0	10.41	
DOLLARS PER TON OF SULFUR REMOVED							91.88	0.0	91.88	
PROCESS COST DISCOUNTED AT 11.6% TO INITIAL YEAR, DOLLARS							28800400	0	28800400	
LEVELIZED INCREASE (DECREASE) IN UNIT OPERATING COST EQUIVALENT TO DISCOUNTED PROCESS COST OVER LIFE OF POWER UNIT										
DOLLARS PER TON OF COAL BURNED							2.31	0.0	2.31	
MILLS PER KILOWATT-HOUR							0.99	0.0	0.99	
CENTS PER MILLION BTU HEAT INPUT							11.02	0.0	11.02	
DOLLARS PER TON OF SULFUR REMOVED							97.20	0.0	97.20	

TABLE C-6

LIME/LIMESTONE SLUDGE DISPOSAL - GYPSUM PROCESS, 1500 MW NEW UNIT, 3.5% S, 7000 HRS CONSTANT ONSTREAM, REGULATED CO. ECONOMICS

FIXED INVESTMENT: $ 10603000

YEARS AFTER POWER UNIT START	ANNUAL OPERATION, KW-HR/KW	POWER UNIT HEAT REQUIREMENT, MILLION BTU /YEAR	POWER UNIT FUEL CONSUMPTION, TONS COAL /YEAR	SULFUR REMOVED BY POLLUTION CONTROL PROCESS, TONS/YEAR	BY-PRODUCT RATE, EQUIVALENT TONS/YEAR WASTE SOLIDS	NET REVENUE, $/TON WASTE SOLIDS	TOTAL OP. COST INCLUDING REGULATED ROI FOR POWER COMPANY, $/YEAR	TOTAL NET SALES REVENUE, $/YEAR	NET ANNUAL INCREASE (DECREASE) IN COST OF POWER, $	CUMULATIVE NET INCREASE (DECREASE) IN COST OF POWER, $
1	7000	94500000	4500000	106800	1488200	0.0	6050100	0	6050100	6050100
2	7000	94500000	4500000	106800	1488200	0.0	6003300	0	6003300	12053400
3	7000	94500000	4500000	106800	1488200	0.0	5956600	0	5956600	18010000
4	7000	94500000	4500000	106800	1488200	0.0	5909800	0	5909800	23919800
5	7000	94500000	4500000	106800	1488200	0.0	5863000	0	5863000	29782800
6	7000	94500000	4500000	106800	1488200	0.0	5816300	0	5816300	35599100
7	7000	94500000	4500000	106800	1488200	0.0	5769500	0	5769500	41368600
8	7000	94500000	4500000	106800	1488200	0.0	5722700	0	5722700	47091300
9	7000	94500000	4500000	106800	1488200	0.0	5676000	0	5676000	52767300
10	7000	94500000	4500000	106800	1488200	0.0	5629200	0	5629200	58396500
11	7000	94500000	4500000	106800	1488200	0.0	5582400	0	5582400	63978900
12	7000	94500000	4500000	106800	1488200	0.0	5535700	0	5535700	69514600
13	7000	94500000	4500000	106800	1488200	0.0	5488900	0	5488900	75003500
14	7000	94500000	4500000	106800	1488200	0.0	5442100	0	5442100	80445600
15	7000	94500000	4500000	106800	1488200	0.0	5395400	0	5395400	85841000
16	7000	94500000	4500000	106800	1488200	0.0	5348600	0	5348600	91189600
17	7000	94500000	4500000	106800	1488200	0.0	5301800	0	5301800	96491400
18	7000	94500000	4500000	106800	1488200	0.0	5255100	0	5255100	101746500
19	7000	94500000	4500000	106800	1488200	0.0	5208300	0	5208300	106954800
20	7000	94500000	4500000	106800	1488200	0.0	5161500	0	5161500	112116300
21	7000	94500000	4500000	106800	1488200	0.0	5114800	0	5114800	117231100
22	7000	94500000	4500000	106800	1488200	0.0	5068000	0	5068000	122299100
23	7000	94500000	4500000	106800	1488200	0.0	5021200	0	5021200	127320300
24	7000	94500000	4500000	106800	1488200	0.0	4974500	0	4974500	132294800
25	7000	94500000	4500000	106800	1488200	0.0	4927700	0	4927700	137222500
26	7000	94500000	4500000	106800	1488200	0.0	4880900	0	4880900	142103400
27	7000	94500000	4500000	106800	1488200	0.0	4834200	0	4834200	146937600
28	7000	94500000	4500000	106800	1488200	0.0	4787400	0	4787400	151725000
29	7000	94500000	4500000	106800	1488200	0.0	4740600	0	4740600	156465600
30	7000	94500000	4500000	106800	1488200	0.0	4693900	0	4693900	161159500
TOT	210000	28350000000	135000000	3204000	44646000					
LIFETIME AVERAGE INCREASE (DECREASE) IN UNIT OPERATING COST							161159500	0	161159500	
DOLLARS PER TON OF COAL BURNED							1.19	0.0	1.19	
MILLS PER KILOWATT-HOUR							0.51	0.0	0.51	
CENTS PER MILLION BTU HEAT INPUT							5.68	0.0	5.68	
DOLLARS PER TON OF SULFUR REMOVED							50.30	0.0	50.30	
PROCESS COST DISCOUNTED AT 11.6% TO INITIAL YEAR, DOLLARS							47321000	0	47321000	
LEVELIZED INCREASE (DECREASE) IN UNIT OPERATING COST EQUIVALENT TO DISCOUNTED PROCESS COST OVER LIFE OF POWER UNIT										
DOLLARS PER TON OF COAL BURNED							1.27	0.0	1.27	
MILLS PER KILOWATT-HOUR							0.54	0.0	0.54	
CENTS PER MILLION BTU HEAT INPUT							6.03	0.0	6.03	
DOLLARS PER TON OF SULFUR REMOVED							53.38	0.0	53.38	